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A new approach to Mixed Circuit Protection

Mixed Circuit Protection (MCP) using Distributed Passive Sensors

Following a severe blizzard in 1888, Hugh Grant, the Mayor of New York, decided to start a global trend of undergrounding power cables to avoid storm damage. Today, global use of underground power cables in transmission and distribution ranges from 20% of the UK's transmission system to 70% of Germany's MV network[1]. Although the costs are higher, installing underground cables is still clearly desirable whether the goal is to reduce the visual impact of overhead lines, avoid storms, or where overhead lines would be impractical, such as densely populated urban areas or to cross rivers.

However, the undergrounding of cables presents significant challenges when things go wrong. Both the complexity and inaccessibility of HV underground cables means that repairs take longer, and are more expensive. For example, a damaged 400 kV underground cable takes 25 times longer to repair than an equivalent overhead line. HV cables (above 220 kV) also tend to experience failures significantly more often than medium voltages (below 220 kV).

Buried cables can occupy a surprisingly large area of land and require access for maintenance and repair for the duration of their life. They are typically routed under roads to avoid excessive land use; however, this leads to disruption of traffic during repairs and contributes to the excess repair time noted above.

Utilities often deploy mixed or hybrid circuits - containing multiple sections of overhead lines and underground cables - when trying to balance cost, convenience, and public opinion considerations. But these mixed circuits present protection challenges which are expensive to address.

Providing granular and fully dependable faulted section identification to distinguish between overhead and underground faults is costly due to the need for civil works, power supplies and telecommunications access for instrumentation at transition points. These cost issues are further compounded if there are multiple cable sections, if they are too far from the substation or if the transition points are simply hard to access. However, an alternative solution is now available in the form of passive distributed sensors which removes these cost and networking issues. We will look at how this works and how it overcomes the challenges outlined above.

"The majority of faults on cables are caused by fluid leaks, faulty joints and accessories, sheath faults, water cooling failures and, most commonly, third party damage. Under fault conditions, between two and six weeks can be required to locate the fault or fluid leak and repair the cable."

1 https://www.nationalgrid.com/sites/default/files/documents/39111-Undergrounding_high_voltage_electricity_transmission_lines_The_technical_issues_INT.pdf

2 https://e-cigre.org/publication/587-short-circuit-protection-of-circuits-with-mixed-conductor-technologies-in-transmission-networks

The technical challenges of protecting mixed circuits

CIGRE report 587 from Working Group B5.232 provides an excellent review of the challenges and the international impact of mixed circuits. Cables and overhead lines – even of equivalent rating and voltage level – have different electrical characteristics, including:

- Overhead lines have higher series inductance than cables.
- The shunt capacitance (i.e. the capacitance to earth) of cables is significantly higher compared to overhead lines, due the close proximity of the phase conductor and sheath earth conductor. This results in much higher charging currents for cables. There will also be higher mutual capacitance between cable phases compared to overhead line phases, as individual cables will typically be installed relatively close within a tunnel or trench.
- In a cable, the impedance to fault will vary non-linearly with fault distance.

- Depending on the sheath and earthing arrangements, cables may also experience "circulating currents" which flow through sections of the sheath, which is caused by current flow in the phase conductor[3].

Mixed circuits will exhibit the combination of multiple cable and overhead line sections connected in series, which is very challenging for impedance-based protection (in addition to the usual challenges with testing and validating such protection schemes for pure overhead line circuits). Analytically resolving the impedance behaviour, particularly on a case-by-case basis for different conductor types, earthing schemes, and other factors, is very complex, as illustrated in Figure 1 and Figure 2. Therefore, using impedance-based protection to accurately detect and locate faults, or even unambiguously determine the faulted section, is practically impossible, and so it is rarely used in practice.

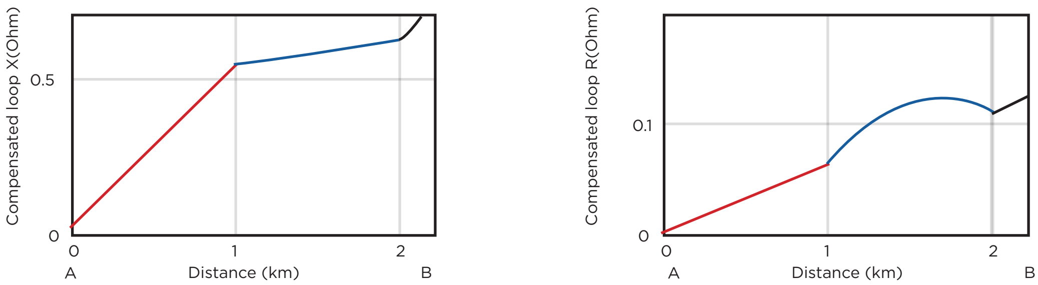


Figure 1: Example of complicated reactive and real impedance vs. distance behaviour (for one overhead line and one cable section)

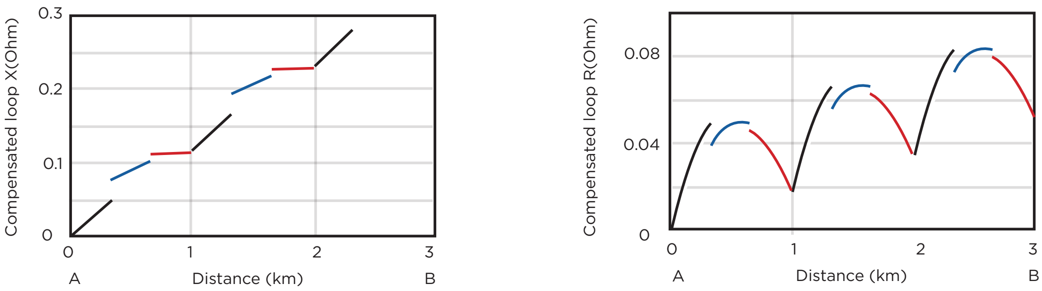


Figure 2: Example of complicated reactive and real impedance vs. distance behaviour (for multiple cable sections)

3 http://www.jicable.org/2007/Actes/Session_B9/JIC07_B97.pdf

Conventional approaches to multizone protection do not provide a practical solution due to the distance of cable transition points from the substation, the lack of power or telecommunications access at remote sites, or the cost of civil works to enable them affordably. This quote from a Danish network operator in CIGRE report 587 sums up the issue: “A general approach regarding transition point power supply and communication has not been available for ‘easy to implement’ solutions to distinguish faults between the overhead line section and the underground cable section.”

Impact of auto-reclose ambiguity

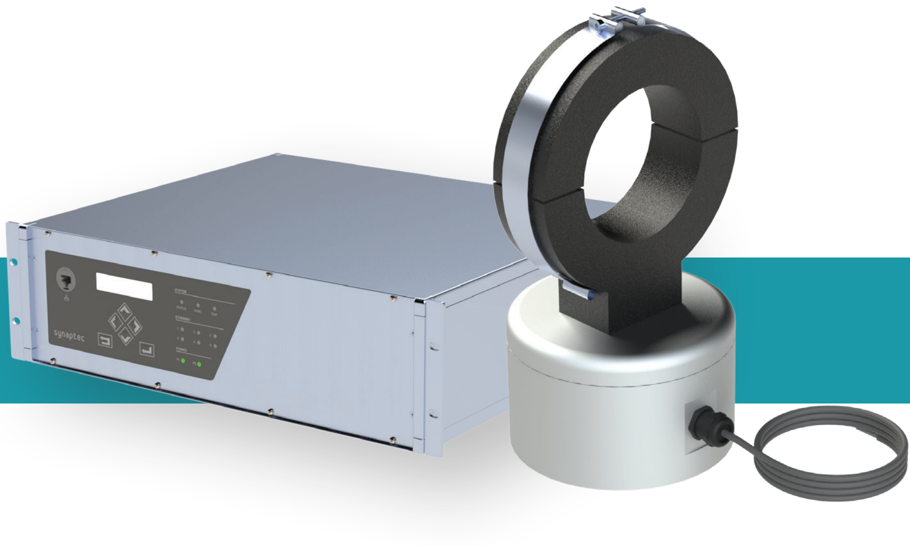
The primary issue with mixed circuits is that impedance-based protection is ineffective or challenging to design and validate, and so is not a dependable way to estimate the distance to fault (especially if the fault is close to a transition point). In turn, this ambiguity around the location of a fault means that conventional auto-reclose procedures cannot usually be applied. Auto-reclose is highly effective at clearing transient faults which are typical for overhead lines and returning the line to service rapidly and automatically. However, faults in cable sections are typically permanent and auto-reclose is therefore detrimental.

The primary issue with mixed circuits is that impedance-based protection is ineffective or challenging to design and validate, and so is not a dependable way to estimate the distance to fault.

Resolving this ambiguity is very important because there are public safety concerns if auto-reclose is handled improperly. For example, accidentally re-energising an underground cable with a genuine fault would likely cause significant damage and potentially lead to an explosion – which is very hazardous in urban areas. Conversely, the absence of auto-reclose for overhead line faults would impact the security of supply of the wider grid for key HV circuits, which would be out of service until a repair could be scheduled.

However, if the cable sections are relatively short, there may be acceptable risk when allowing auto-reclose without discrimination – and this approach is used in some countries.

The transition point may need specific protection equipment such as surge arrestors. In some cases, controlled “point of wave switching” is used to avoid over voltages when energising the cable sections (due to arcing at the circuit breaker contacts which can cause wear of the breaker contacts). However, these interventions are relatively



rare due to being impractical and costly to install at remote locations because an auxiliary supply is required for the relays and other active electronics.

Using Passive Sensors Networked Through Existing Fiber To Enable Wide Area, Multizone Protection

Optical fiber is widely available in HV power grids, and provides direct access from substations to remote transition points. This fiber may be used as a network to connect distributed sensors in series over wide areas to provide granular visibility of mixed circuits by instrumenting both sealing ends of multiple cable sections – see Figure 3.

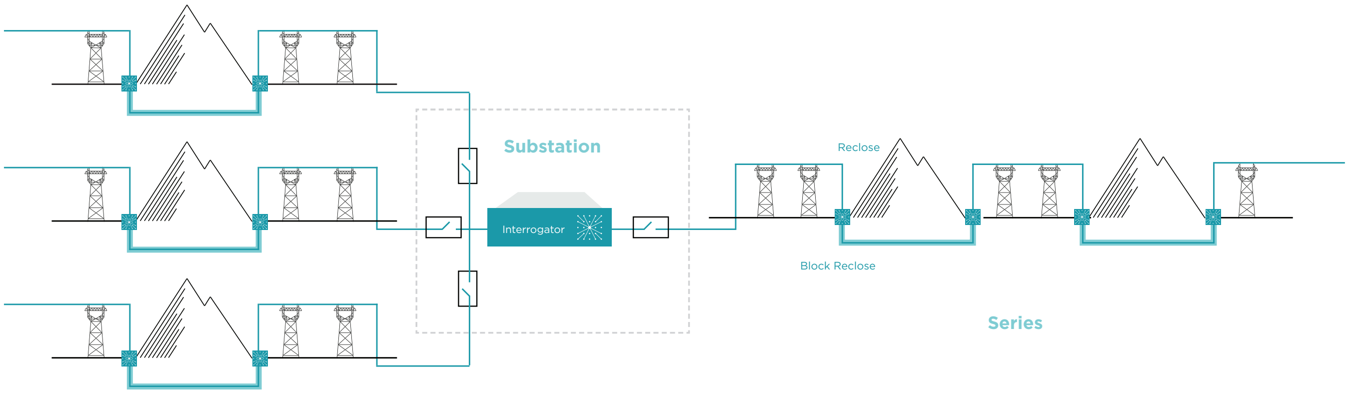


Figure 3: Centralised protection solution for mixed circuits using passive, distributed sensing

Synaptec produces distributed sensors which can straightforwardly facilitate multiple measurements of current throughout mixed circuits. A multi-zone differential protection system for such circuits can be readily constructed by installing (or retrofitting) passive current sensors at the line ends and at all cable termination points. A single interrogation system is installed at one end of the line, which is responsible for interrogating the entire array of sensors from a single end, making it trivial to solve the issue of ambiguous faulted section identification. Multiple cable sections in series or in parallel can be instrumented simultaneously using the same system, reducing capital costs significantly. It is important to note that the sensors installed are entirely passive, affording several advantages when compared to conventional or NCIT (Faraday effect-based) instrumentation: there are no power supplies, telecommunications infrastructure, multiplexers, or active components such as computers, which must be installed at any remote measurement locations. Therefore, the civil infrastructure expenditure that would be associated with instrumenting these locations using traditional sensing technologies is removed.

Further benefits from Synaptec's distributed sensor-based approach to this application include enhanced security, and more robust and reliable measurements over time. Security is enhanced because there is effectively no data outside the substation, with sensors networked to one central interrogator by encoded light through fiber which cannot be eavesdropped or disrupted. This avoids issues commonly associated with 4G-based or switched IP packet networks. Robustness and reliability come from passively measuring on the secondaries of industry-standard CTs, which offer a wide operating temperature range and user-specified accuracy.

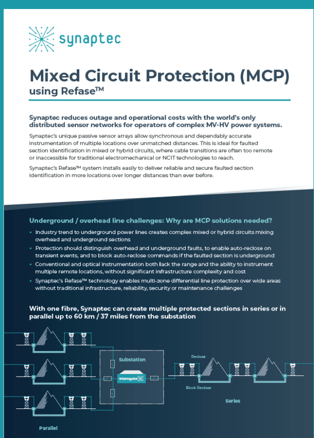
Using familiar form factors, they are easy to install or retrofit anywhere. Additionally, Synaptec's passive sensors are not vulnerable to EM interference and feature built-in temperature compensation to ensure protection-class accuracy over decades of operation with no need for periodic recalibration or maintenance.

Synaptec's distributed sensor platform is also suitable for granular, multi-zone protection for many complex circuit types, including multi-branch circuits, lines with series compensation, or long, jointed cable systems where soil resistivity changes over distance, affecting fault resistance.

This approach to instrumentation securely enables superior multi-zone faulted section identification in many locations for less capital cost than conventional monitoring, with no compromise on accuracy or reliability over time, while avoiding the limitations of NCIT-based techniques. The same interrogation scheme is upgradeable to include additional condition monitoring benefits such as sheath current monitoring, termination overheating alarms, and power quality analytics to provide earlier warnings of impending equipment failure as well as rapid and discrete post-event response to faults. This combines to reduce downtime and optimise maintenance costs at the most remote and inaccessible locations in a scalable and more affordable manner.

For further information please visit synapt.ec or email info@synapt.ec

Download the brochure for more details



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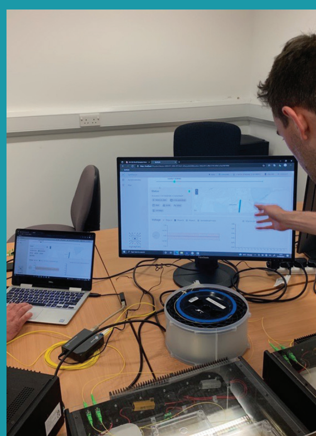

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