ARTICLE

Reclosing on Hybrid Sub-Transmission Systems

The use of hybrid sub-transmission systems—a combination of overhead lines and underground cables—has increased in recent years due to rapid urbanization and the need for an efficient use of all urban space while preserving views. While underground cables are less susceptible to faults due to their lack of exposure, they are not designed to withstand multiple reclosing operations and the extruded-dielectric cables that are designed to withstand a reclosing operation must be solidly grounded. Faults in underground cables tend to be permanent rather than temporary—and unlike overhead lines, where reclosing technology effectively clears temporary faults, underground cable faults require a different approach to avoid further damage.

There is currently no clear guidance or standard related to auto reclosing on a hybrid sub-transmission system. And if auto reclosing is performed on a permanent fault condition, it may cause excessive overcurrent and switching surge, which can generate a serious impact on the whole sub-transmission system and even cause an explosion. Due to this, many utilities worldwide do not allow auto reclosing or only apply it very restrictively on a hybrid sub-transmission system based on their practice.

When dealing with hybrid systems, it's critical to accurately identify the location of the fault before initiating any reclosing operation. Reclosing on a faulted underground cable could exacerbate damage, leading to costly repairs and prolonged outages.

This article explores the fundamentals of reclosing on systems that involve both overhead and underground cables.

Causes of Permanent Faults in Underground Cables

With the aforementioned growth in the use of hybrid systems, the need for understanding the intricacies of underground cables and the proper protection schemes to protect these hybrid power systems is paramount.

Permanent faults in underground cables are typically caused by external damage or internal insulation degradation. Some of the potential causes of permanent faults include:

- **External Activity:** Underground cables may be damaged by digging or damage to cable accessories.
- **Insulation Degradation:** While external factors often contribute to insulation damage, there are also several internal factors:
  - **Aging:** Cables can become brittle over time, resulting in cracks and faults.
  - **Moisture Ingress:** Water penetration into the cable's insulation can cause significant damage.
  - **Voids in Paper Cables:** Paper-insulated cables may develop voids as the paper dries out, leading to electrical discharge and failure.
  - **Excessive Heating:** Overheating can weaken insulation, particularly in areas with poor ventilation or cooling.

Common Underground Cable Types and Their Failure Modes

Here are some of the common types of cables used in underground systems and their respective failure modes:

High-Pressure Fluid-Filled Cables (HPFF)

- **Usage:** Typically used for underground transmission.
- **Insulation:** These cables use kraft paper or laminated paper polypropylene for insulation, which is impregnated with oil and enclosed within pressurized steel pipes.
- **Protection:** High pressure, typically over 200 PSI, helps to fill any voids that may form, preventing electrical discharges that could cause faults. Additionally, the steel pipes are safeguarded by cathodic protection to help prevent corrosion.
- **Failure Mode:** These systems can have gas build up in the dielectric fluid which can lead to a catastrophic failure and potential pressure event.

Ethylene-Propylene Rubber (EPR) Cables

- **Usage:** Common in underground transmission and distribution.
- **Insulation:** EPR cables are insulated with ethylene-propylene rubber.
- **Failure Mode:** EPR cables are vulnerable to permanent faults due to external damage or insulation degradation, and reclosing on these faults can lead to further damage resulting in extensive replacement work to surrounding cable areas.

Cross-Linked Polyethylene (XLPE) Cables

- **Usage:** Common in underground transmission and distribution.
- **Insulation:** The insulation material is cross-linked polyethylene.
- **Failure Mode:** Like EPR cables, XLPE cables are subject to permanent faults that cannot be cleared by reclosing. Reclosing on these cables will result in a wider spread of damage to the cable system.

Advanced Automation and Detection Techniques

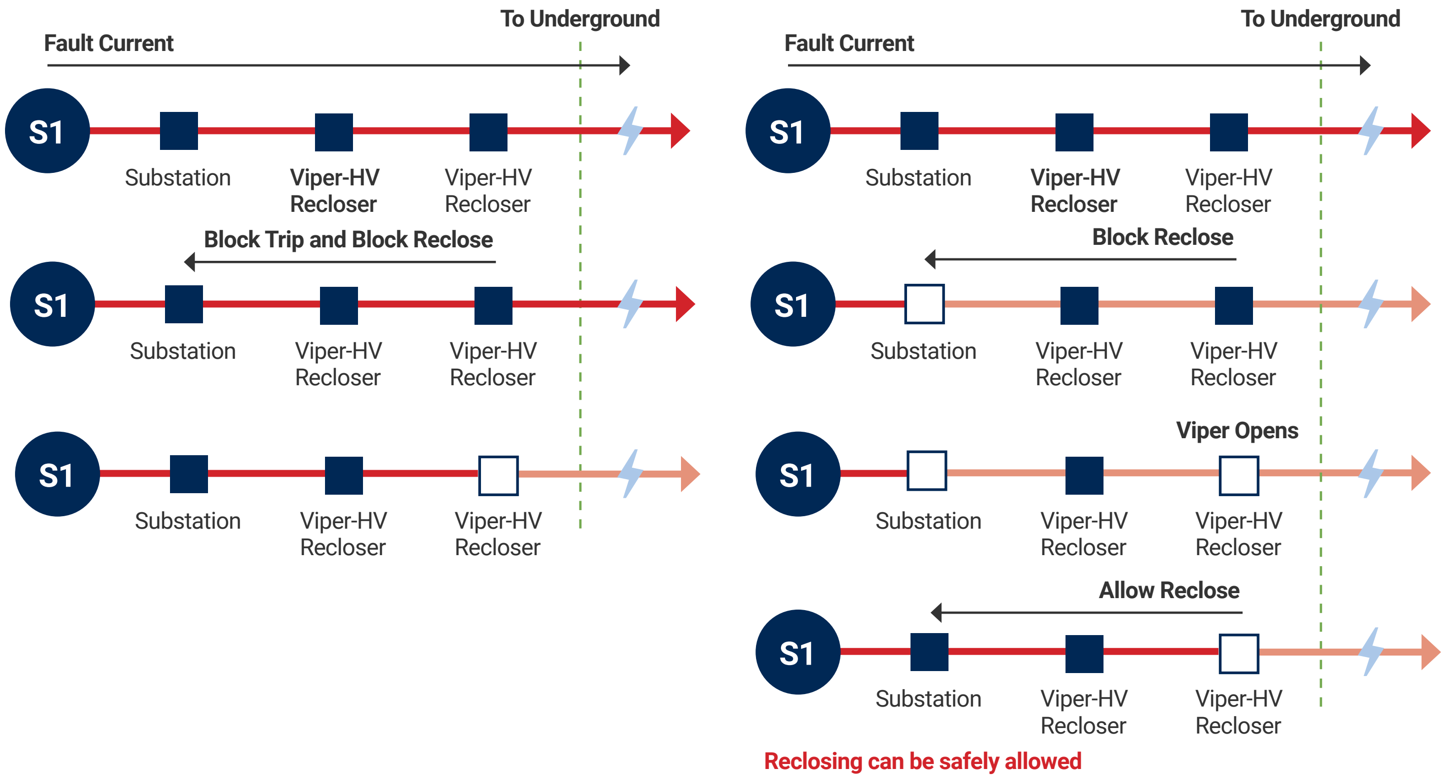
In hybrid systems, preventing reclosing on underground cables is crucial to avoid serious damage, including potential explosions. Advanced automation and monitoring techniques play a key role in achieving this. To implement these advanced strategies effectively, understanding the role of relay coordination and communication schemes is essential for ensuring precise fault detection and reliable system operation.

Relay schemes play a critical role in hybrid systems, using advanced monitoring to determine whether a fault is in the underground cable or the overhead line. By comparing the current flowing into and out of the cable, operators can assess where the fault lies. If the sum of the currents is close to zero, it indicates the fault is likely not in the underground cable, allowing reclosing to proceed on the overhead portion. However, a significant current imbalance suggests a fault in the underground cable, in which case the breaker should lock out to prevent reclosing and avoid further damage.

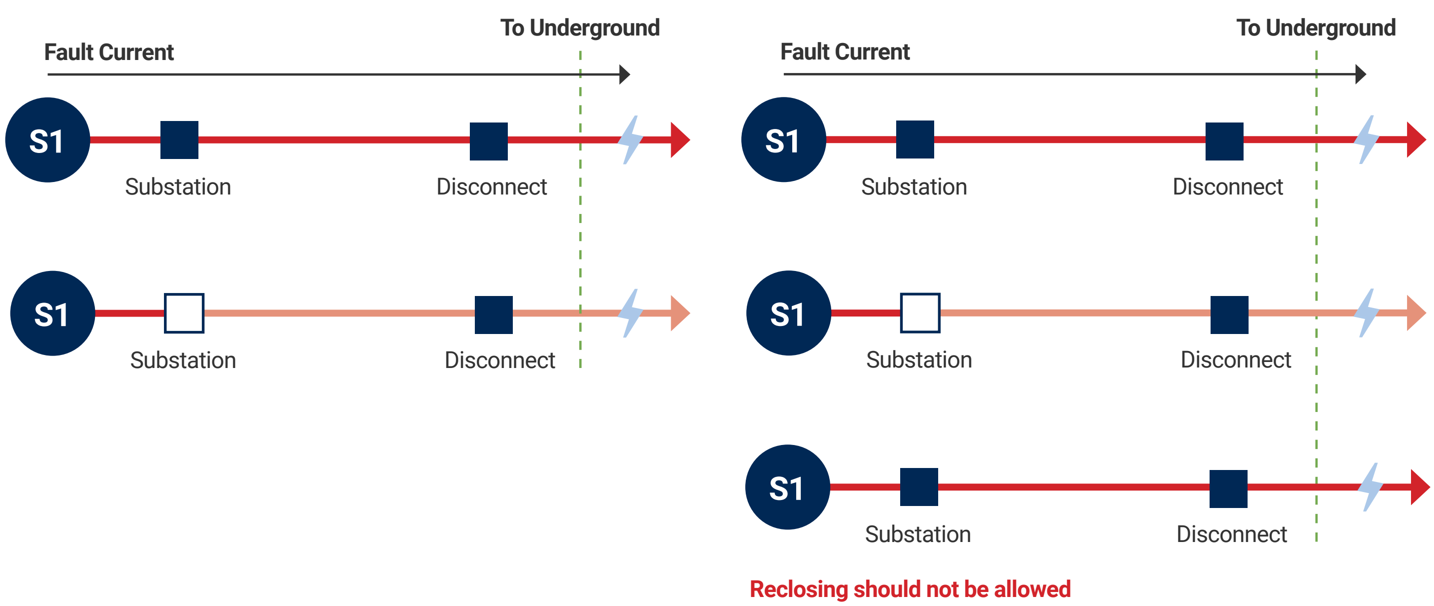
Blocking schemes enhance coordination by enabling seamless communication between fault-detecting relays and their upstream or downstream counterparts. Using peer-to-peer communication protocols like IEC 61850 GOOSE ensures reliability and speed in fault response, minimizing potential disruptions across the network.

Directional Comparison Blocking (DCB) is one such communication-based protection scheme that provides high-speed tripping for faults. DCB is an effective solution where traditional step-distance protection may not provide proper coordination. In a directional comparison blocking scheme a relay sends a blocking signal to an upstream relay if it detects a fault in the forward direction, indicating that the fault is outside of the upstream relay's protected zone. The logic is programmed in each relay such that it trips when it sees a fault in the forward direction and does not receive a blocking signal from its downstream peer.

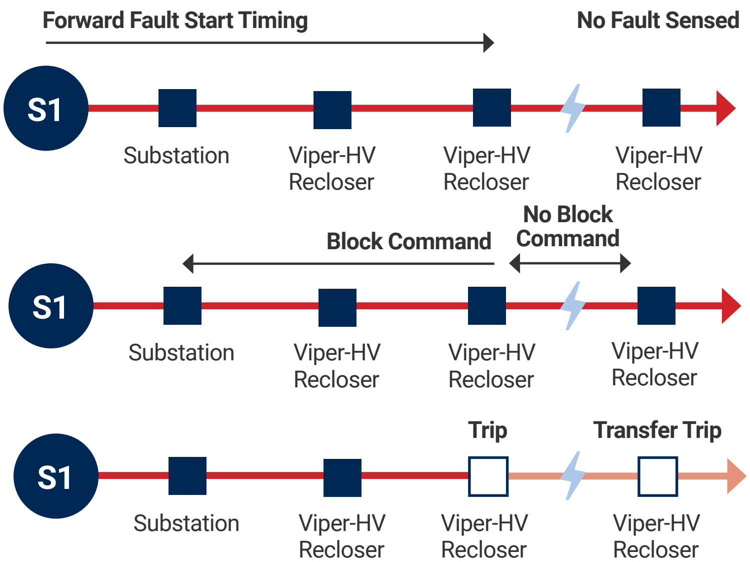
Hybrid System with Viper®-HV Recloser at Transition



Hybrid System with NO Viper-HV Recloser at Transition



Direction Comparison Blocking (DCB) Scheme



In a Fault Location, Isolation, and Service Restoration (FLISR) implementation using DCB, the relay upstream of the fault will then send a transfer trip signal to its adjacent downstream peer to trip and isolate the faulted section. Once the switch on the opposite end of the faulted line is open it will send a close command in the opposite direction of the faulted line (downstream). This close command will be passed from relay to relay until it reaches an open switch. This switch will then close if it has a live alternate source.

Revolutionizing Hybrid Systems: The Role of Viper®-HV Recloser in Reclosing Operations

Utilizing advanced reclosing technology is important for many reasons, including precise fault location for rapid power restoration. One of the primary challenges utilities face when restoring power after an outage is finding the fault that caused it. Existing solutions can approximate the location of a fault, but still require utility personnel to devote precious time to pinpointing its exact location—often in harsh weather conditions—resulting in longer restoration times and frustration for customers and regulators.

G&W Electric designed the Viper-HV, the world's first sub-transmission pole-top recloser, in collaboration with utility customers to meet market needs. The Viper-HV recloser can be used for a wide variety of applications previously unavailable at the sub-transmission voltage class, such as overcurrent protection, automation, and sectionalizing outside of the substation. Additionally, it offers overcurrent protection through fault isolation and automatic restoration for temporary faults on overhead sub-transmission lines. The relative ease of adding Viper-HV Recloser installations allows system operators to sectionalize the hybrid system more finely and more easily detect a fault's location at the transitions between overhead and underground.

The Viper-HV overhead recloser can be equipped with controllers featuring built-in intelligence for precise fault location, which complements the advanced automation and protection schemes discussed earlier. These controllers use impedance-based algorithms and traveling wave fault location determination, enabling faster and more accurate identification of faults, particularly on longer sub-transmission lines. By integrating these features, the Viper-HV Recloser enhances the relay coordination and fault isolation strategies critical for preventing damage to hybrid systems, ensuring both efficiency and reliability in system restoration.

Another significant benefit of advanced overhead recloser technology is the potential to avoid the necessity of adding new substations. When a new feeder and circuit breaker need to be added to a sub-transmission system substation, the Viper-HV overhead recloser can increase the speed and lower the cost. Traditional circuit breakers need to be ground-mounted on a concrete pad, which takes up space that many substations don't have and involves a permitting process that can be time-consuming. In contrast, the Viper-HV overhead recloser can be mounted on the already grounded metal frames available at most substations, taking no additional space and avoiding a lengthy permitting process.

The introduction of the G&W Electric Viper-HV recloser marks a significant advancement in the realm of system protection and automation. Hybrid systems involving underground cables require more careful handling due to the permanent nature of most underground faults, and with the Viper-HV recloser's advanced fault detection and automation capabilities, utility companies can significantly reduce outage times, prevent unnecessary damage to underground cables and improve overall system reliability.

The Viper-HV recloser exemplifies how advanced technologies can address the unique challenges of hybrid sub-transmission systems. By combining precise fault location, streamlined installation, and enhanced automation, it provides utilities with the tools needed to protect critical infrastructure and maintain reliable service. As hybrid systems continue to grow in complexity, integrating such innovative solutions will be essential for ensuring long-term system resiliency and efficiency.

A Cautionary Tale

To underscore the implications of reclosing on the underground portion of a hybrid system, we offer the following story of a lessoned learned by a large utility company:

One evening, a utility identified a fault on a 72.5kV circuit. The circuit covers a downtown area with both commercial and residential customers, spans five miles and is composed of both overhead and HPFF underground segments to best support the service area. Historically, the faults have been temporary on the overhead segments and reclosing had cleared the issue. However, this evening, the fault was on the underground segment.

The breaker was used to try to reclose into the fault, without adequate fault locating technologies. This is when disaster struck. The fault was on the HPFF underground segment. The reclosing activity created a pressure event that resulted in catastrophic damage to the existing HPFF infrastructure. All the cable accessories needed to be replaced along with significant civil work to fix any warped structures and pipes. The work took almost three months to completely resolve the issue due to the need for replacing the damaged equipment.

If advanced fault location had been done and prevented reclosing on the circuit, the work would have been limited to a short cable pull and some splice work.

Ensuring Resiliency in Hybrid Power Grids

Hybrid sub-transmission systems, with their mix of overhead lines and underground cables, present unique challenges that demand a thoughtful balance of protection, automation, and innovation. The risks associated with reclosing on underground cables underscore the need for precise fault detection and advanced relay coordination. By leveraging technologies such as the Viper®-HV recloser, utilities can better manage these challenges, reducing downtime, minimizing infrastructure damage, and enhancing overall reliability.

As urbanization accelerates and power grids become increasingly complex, adopting forward-looking solutions will be essential for ensuring safe and efficient energy delivery. Utilities that embrace these advancements not only protect their infrastructure, but position themselves to meet the growing demands of modern energy systems. The future of hybrid sub-transmission lies in blending proven practices with cutting-edge innovations to create resilient, adaptable networks that serve the needs of both today and tomorrow.

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