Line Differential Protection at the Transmission Edge

TECHNICAL BRIEF

Applying Viper®-HV Recloser with Ingeteam INGEPAC EF LD Relays to Add Protection Terminals at Transmission Taps, Renewable Interconnections, Industrial Sites, and Remote Line Protection Points

Overview

The Viper-HV recloser gives utilities, transmission operators, and project developers a practical way to add interruption, current measurement, and relay-based protection at transmission-edge locations without building a conventional substation or switching station terminal at every site. When paired with the INGEPAC EF LD relay, the Viper-HV recloser can serve as the field platform for a line differential protection terminal, allowing protection to extend to renewable interconnections, industrial taps, and remote transmission locations where a conventional station footprint may be difficult, costly, or slow to deploy.

The Protection Problem

Transmission networks are being asked to connect renewable generation, serve remote industrial loads, reinforce existing corridors, and improve reliability while limiting project footprint, civil works, and outage windows. These requirements become particularly important at renewable generation interconnections, battery energy storage installations, industrial facilities, and remote line locations where extending conventional substation infrastructure may be difficult to justify.

The protection challenge can become more complex where inverter-based resources are involved. Solar generation, wind generation, and battery energy storage systems control fault current electronically. Their fault-current contribution can differ from conventional rotating-machine behavior, which may require additional review of distance and directional overcurrent protection applications.

Line current differential protection addresses this challenge by defining a specific electrical zone and evaluating current balance across all terminals simultaneously. The protection decision is based on current entering and leaving the zone rather than relying primarily on impedance estimates, current magnitude, or power-flow direction. Historically, applying line differential protection at a transmission tap, renewable interconnection, industrial spur, or remote line location required a substation at every terminal of the protected zone.

How Line Differential Protection Works

How A Differential Zone Is Defined and Monitored

Line differential protection treats a defined section of the transmission network as a zone with measurable boundaries. An INGEPAC EF LD terminal is placed at each end or at each terminal in a multi-terminal zone, and synchronized current measurements are exchanged among the relay terminals.

Under normal operating conditions and for faults outside the protected zone, the current entering through one or more terminals is balanced by current exiting through the others. The differential sum remains low and the protection remains stable.

For a fault inside the zone, current from one or more terminals flows toward the fault and does not pass through another zone boundary. The resulting differential current rises above the operating threshold and the differential element initiates a trip.

Bidirectional Current Flow

This zone-based principle is particularly useful where generation and load can cause power to flow in more than one direction. In a renewable generation interconnection, for example, the site may export power to the transmission network during normal production while current direction may change under other operating conditions.

Differential protection evaluates the balance of current across the entire defined zone rather than depending on a single measurement point to determine fault direction or apparent impedance. As generation output and network conditions change, the electrical boundaries of the differential zone remain the same.

INGEPAC EF LD Differential Functions

The INGEPAC EF LD provides phase differential, ground differential, and restricted earth fault differential protection for transmission lines. Distance and directional overcurrent functions are also available for additional protection.

The relay supports two-terminal and three-terminal line differential schemes, allowing the protection architecture to be applied to simple point-to-point connections as well as tapped or branched configurations with an additional terminal.

For applications that include a transformer within the protected zone, the INGEPAC EF LD can account for transformer phase shift, transformation ratio, and zero-sequence behavior. This allows the protected zone to be designed around the electrical equipment required for the particular interconnection rather than requiring the transformer to be excluded in every application.

Ground Fault Sensitivity

The INGEPAC EF LD provides ground differential protection for applications where fault characteristics or limited fault-current contribution may challenge conventional ground protection.

This can be relevant to renewable generation and other inverter-based resource interconnections, where the connected resource may provide limited or no zero-sequence fault current depending on the inverter, transformer connection, and system grounding. Ground differential protection with optional directional supervision can provide another protection element for evaluating faults within the defined zone.

Inverter-Based Resource Considerations

Differential protection can provide dependable protection in inverter-dominated applications because operation is based on current balance within the protected zone. Protection settings still need to be reviewed against the expected fault-current contribution and operating characteristics of the connected inverter technology.

Viper-HV® Recloser as the Field Terminal

Viper-HV recloser is a pole-mounted, solid-dielectric recloser with ratings available up to 72.5kV. Magnetically actuated vacuum interrupters, internal multi-ratio current transformers, and line-side voltage sensors are integrated into the device, allowing it to serve as a self-contained field platform for protection and automation.

The Viper-HV recloser's internal current transformers provide the current measurement required by the INGEPAC EF LD. When the relay issues a trip, reclose, or lockout command, the Viper-HV recloser opens or closes the circuit as configured under the utility's protection philosophy.

This architecture is best suited to locations where the protected electrical zone can be clearly defined, selective fault clearing is required, and constructing a conventional station terminal may be difficult to justify based on cost, schedule, site requirements, or project scope. It is not a universal substitute for substation-based protection. It provides another way to establish a transmission protection terminal at selected line locations where protection previously required significantly more infrastructure.

The same field platform also provides remote operability and additional network visibility. Current, voltage, status, and fault information can be integrated into SCADA. This gives system operators information and remote control at transmission locations that may previously have had little or no real-time instrumentation.

System-Level Validation

Conventional transmission protection is built from independently qualified components. Circuit breakers are tested as standalone devices under breaker standards such as IEEE C37.04, C37.06, and C37.09. Protection relays are tested independently under relay-specific standards such as the IEEE C37.90 series. Those standards verify how each component performs on its own, not how the interrupter, control, protection logic, and wiring behave once they are wired together.

That combined behavior is usually confirmed late, during site acceptance testing or field commissioning, which is also the most schedule-constrained part of a project.

Viper®-HV recloser is engineered, assembled, and validated as one system before it leaves the factory. The interrupter, control, protection logic, and wiring are tested together rather than qualified separately and integrated later. One example of this is Simulated Surge Arrester Operation testing under IEEE C37.60, which applies a simulated lightning-induced surge to the assembled recloser and control and confirms the control does not misoperate and that the system retains full function afterward. This type of system-level validation helps reduce the installation risks that might otherwise be discovered later during site acceptance testing or field commissioning of separately sourced equipment.

This matters most at taps and mid-line locations, which are often remote, difficult to access, and constrained by limited outage windows. Validating the system before shipment moves integration risk out of the field, where a return visit is expensive and slow, and into the factory, where it is not.

Communications Architecture

Line differential protection depends on synchronized current measurements from all terminals of the protected zone. Communications architecture is therefore part of the protection scheme itself.

The INGEPAC EF LD supports multiple communications options, including serial communications, optical fiber, Ethernet, and C37.94 interfaces. Available configurations can use a single communications channel or redundant channels where the application requires additional availability.

Synchronization options include IEEE 1588v2 Precision Time Protocol, IRIG-B, Simple Network Time Protocol, and propagation-delay synchronization methods where applicable. The appropriate method depends on the selected communications architecture and project requirements.

In a two-terminal application, the communications path exchanges synchronized current measurements between the station terminal and the Viper-HV recloser field terminal. In a three-terminal scheme, measurements from all three terminals are included in the protected-zone calculation.

Communications channel availability, redundancy, synchronization, and communications-failure behavior should be evaluated during protection design with the same rigor as Viper-HV recloser placement and relay settings. A communications limitation identified late in the project can change the feasible protection architecture, making early evaluation important for project schedule and design.

Backup Protection on Communications Failure

The INGEPAC EF LD includes five-zone distance protection and directional overcurrent functions that can operate continuously or be configured to provide backup protection if the differential communications channel becomes unavailable.

This allows protection coverage to remain available during a communications interruption, although the operating characteristics and selectivity may differ from full differential protection. When communications and synchronization are restored, the relay can be configured to return to differential operation according to the selected protection scheme.

FIELD APPLICATION

Adding a Renewable Tap to an Existing 69kV Transmission Line

A utility plans to add a renewable generation tap to an existing 69kV transmission corridor. The new facility connects at a remote tap point on the line rather than at an existing station.

The application requires selective protection for the tapped line section, but the utility does not want to construct a full switching station. The differential zone must include current measurements from the source end, the tap point, and the main transmission corridor downstream of the tap. The utility establishes a three-terminal line differential scheme. One INGEPAC EF LD terminal is installed at the source substation, a second terminal is installed at the new tap using a Viper®-HV recloser as the field interrupting device, and a third terminal is installed at the existing load substation downstream of the tap.

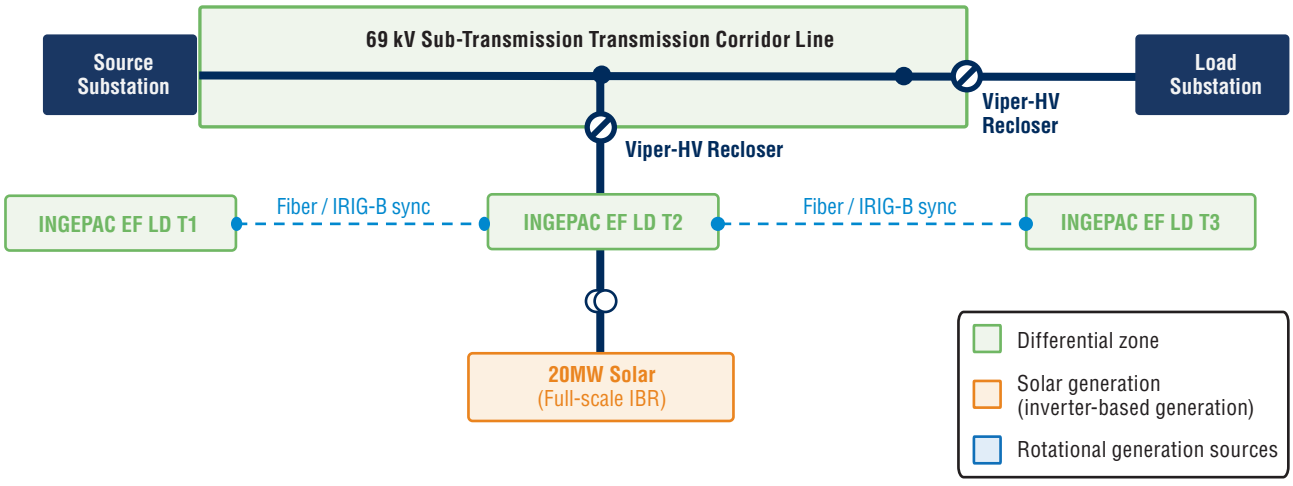
Each terminal measures the current entering or leaving the protected zone at its respective boundary. The three INGEPAC EF LD terminals exchange synchronized current measurements over the selected communications architecture, allowing the relay system to evaluate the complete three-terminal current balance.

At the tap, the Viper-HV recloser's internal current transformers provide the current measurement for the field relay terminal. The relay controls the Viper-HV recloser so the tap can be disconnected when required by the protection scheme. The source and downstream terminals trip their associated interrupting devices according to the utility's line protection philosophy.

The result is a protected three-terminal line section that includes the existing source terminal, the new tap terminal, and the downstream mainline terminal. The Viper-HV recloser allows the tap point to become a true protection terminal without requiring construction of a conventional switching station at that location.

Three-Terminal Line Differential Protection — Viper®-HV Recloser + Ingeteam INGEPAC EF LD

87L Differential Zone — T1 to T2 to T3



Event 1: Internal Line Fault During Solar Generation

During a period when the renewable site is generating, a fault occurs on the 69kV line inside the three-terminal differential zone.

The source terminal, tap terminal, and downstream main-line terminal each measure the current at their respective boundaries of the zone. Depending on system conditions, fault current can be supplied from the source, from the renewable tap, from the downstream corridor, or from a combination of those sources.

Because the current entering the protected zone does not balance with current leaving the zone, the differential calculation detects an internal fault. The decision is made using the synchronized current measurements from all three terminals, not from a single directional or impedance measurement at the tap.

The INGEPAC EF LD terminals initiate the configured protection action. The source breaker, the tap Viper®-HV recloser, and the downstream interrupting device trip as required to isolate the faulted section and remove contributing sources.

The faulted section is isolated using three protection terminals. The Viper-HV recloser provides the field interruption and current measurement at the tap, which is the added terminal that makes differential protection practical for the tapped transmission application without building a switching station at that location.

Fault records, oscillography, current measurements, and device status can then be used by protection engineers and system operators to evaluate the event and support restoration.

Event 2: Tap-Side Fault Between the Solar Facility and Viper-HV

A fault occurs on the tap section between the solar generation facility and the Viper-HV recloser. This fault is outside the main transmission corridor but inside the generation tap that connects to the line.

The Viper-HV recloser detects the fault using directional fault protection configured to look into the tap. Because the fault is on the generation-side connection, the Viper-HV recloser opens to isolate the tap from the transmission line.

The source terminal and downstream main-line terminal remain stable because the fault is not on the protected main corridor. The differential scheme does not need to trip the entire three-terminal line section for a fault that can be cleared selectively by the tap device.

This operation prevents the solar tap fault from escalating into a wider transmission outage. The tap is disconnected, the generation source is isolated from the line, and the main transmission corridor can remain in service if the rest of the protection system confirms the fault is limited to the tap section.

Use Cases

Protection and Deployment Value

These two events demonstrate how the Viper®-HV recloser can support both main-line differential protection and selective tap isolation on an existing transmission corridor.

For a differential fault on the protected transmission line section, the INGEPAC EF LD terminals use synchronized current measurements from the source, tap, and downstream main-line terminals to identify an internal-zone fault and initiate the required trips. For a fault between the solar facility and the Viper-HV recloser, the recloser operated on directional fault protection to isolate the tap while allowing the main transmission corridor to remain in service.

Together, the INGEPAC EF LD and Viper-HV recloser provide.

- A defined three-terminal differential zone for an existing transmission line with a new generation tap
- Selective clearing for internal main-line faults using the source, tap, and downstream main-line terminals
- Directional tap-side protection that can isolate a fault between the solar facility and the Viper-HV recloser
- Reduced exposure to wider transmission outages for faults limited to the generation tap
- Current, voltage, status, and event visibility at the field location
- Backup protection functions available for utility-specific protection philosophy and communications-failure cases
- A compact field installation that can reduce the infrastructure required at selected interconnection points

The application does not eliminate the need for system studies, relay coordination, communications engineering, or utility-specific protection design. It changes where one of the required protection terminals can be located and adds a practical way to isolate tap-side faults without unnecessary tripping of the main transmission corridor. By putting transmission-rated interruption, measurement, and field operability on the line structure, the Viper-HV recloser allows the tap point to become part of the protection scheme while requiring substantially less infrastructure at that location.

For more information

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