HIGH-SPEED FALLING CONDUCTOR PROTECTION

TWO-PART INTERVIEW SERIES

Part 1: Protection

A CONVERSATION WITH

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GE's GridNode High-Speed Falling Conductor Protection (HFCP) provides a reliable solution in detecting, de-energizing, and isolating a broken overhead power line using secure wide-area measurements prior to the conductor touching the ground.

In this two-part interview series, hear our experts Hasan Bayat and Yujie Yin share their expertise as they answer key questions on the serious risks involved by an energized broken conductor on the ground and the benefits of HFCP solutions.

Hasan Bayat

Hasan is a Lead Customer Application Engineer with GE's Grid Solutions. He has more than ten years of academic and industrial work experience in power system studies and specializes in power system protection, automation, and control; microgrid control and protection; and hardware-in-the-loop testing.

Hasan received his PhD from the Electrical and Computer Engineering department at Western University in 2018. His thesis focused on grid integration of large-scale PV farms and battery energy storage systems. He has published several publications in IEEE transactions, international journals, and conferences from industrial and academic perspectives.

Yujie Yin

Yujie is a Senior Application Engineer with GE's Grid Solutions. He has more than 20 years of experience in power system protection and control applications, studies, analysis, and testing. He is also a senior member of IEEE, a CIGRE B5 WG member, and a licensed professional engineer in the province of Ontario.

Yujie's areas of expertise include microgrid protection and control, remedial action schemes, IEC61850 digital substations, phasor measurement, and synchrophasor applications. He has worked on many utility projects in North America and has authored/co-authored more than 15 technical papers published in IEEE journals and other major conferences.

Yujie received his PhD in Electrical Engineering from Mississippi State University in 2020. He also holds Bachelor of Computer Science and Master of Electrical Engineering degrees from Western University and a Bachelor of Electrical Engineering degree from Hefei University of Technology in China.

PART 1: PROTECTION

Let's start off with some basics. What is HFCP?

Hasan: HFCP stands for High-speed Falling Conductor Protection. In short, when an overhead powerline breaks, the energized conductor can fall and cause serious damage and even risk igniting a fire. HFCP detects and isolates broken conductors before they fall to the ground using real-time monitoring and control system over a high-speed communication network.

What happens when a conductor breaks?

Hasan: Arcing may happen as soon as the conductor starts to separate. The open phase condition results in an unbalance and asymmetrical current flows in the system. The conductor might remain hanging in the air, touch the ground or be grounded through a supporting structure, or lead to a high-impedance fault that is difficult to detect. A protection relay might also attempt to reclose as it does not know whether the fault is temporary or permanent.

Failure to detect a falling broken conductor could cause a potential arcing ground fault and a potential ignition point for wildfires and pose a significant risk to people, wildlife, or infrastructure in the vicinity.

What detection methods are already in use?

Yujie: There are a few different methods being used in the industry, each with its pros and cons. The voltage-based method, for example, use voltage measurements at the feeder head and branches. When a single-phase loss of voltage is detected, it may claim an open phase condition. However, this needs to coordinate with protection relays as upstream phase-ground fault may also cause loss of voltage.

The I2/I1 method works by calculating the ratio of negative sequence to positive sequence current. The limitations of this method are that it's prone to fail under low-load conditions and can't incorporate the impact of distributed energy resources (DERs).

The Hi-Z fault detection method incorporates a signature-based expert pattern recognition system. This method works only after the conductor touches the ground or other objects, has lower sensitivity, and longer detection time.

Lastly, there are also mechanical methods where the guard wire grid holds the conductor and thereby prevents it from falling to the ground. Cost considerations make this solution less attractive.

So then what's the need for HFCP when other Hi-Z protections are already available?

Hasan: Hi-Z protection only operates after the conductor touches the ground and causes a fault, whereas HFCP operates before the conductor reaches the ground (typically within 500 ms) and ultimately avoids a fault condition, stressing the system, or possible ignition point.

The Hi-Z approach incorporates a signature-based expert pattern recognition system. Harmonic energy levels in the arcing current and a sophisticated expert system assure security and dependability for detection of Hi-Z faults.

Hi-Z protection can detect events only after a fault condition has occurred, whereas HFCP can detect events prior to the conductor reaching the ground and avoid a fault condition from developing. Overall, Hi-Z protection and HFCP are complementary technologies.

How much time does it take to detect a falling conductor?

Yujie: The minimum tower height for an 11kV voltage level or higher is around 5.6m or 18 feet, which results in an average falling time of 1.06 seconds. For transmission systems, the detection time may be longer due to a higher conductor height.

Can you describe the operating principle of GE's HFCP?

Hasan: When a conductor breaks, the load or line impedance can change significantly as compared with the healthy, pre-fault condition. The impedance change ratio (ICR) is calculated by subtracting the pre-fault impedance from the current impedance and then normalizing it by the pre-fault impedance.

Then, the ICR for phase-to-ground and phase-to-phase impedances are also calculated.

The algorithm uses the ICRs calculated from synchrophasor measurements, which are streamed from feeder protective relays, reclosers along the feeder, or dedicated Phasor Measurement Units (PMUs). The algorithm declares a falling conductor condition when certain ICRs for a distribution feeder exceed a threshold (an adjustable setpoint, defaulted at 0.18).

A voltage-based detection scheme is also added for PMUs located along the feeder. It can detect open phases upstream of the PMU by measuring a low voltage and low current on one phase, and healthy voltages on the other two phases. This has the potential to improve the coverage of the overall solution and identifies the area where the fault is located.

How does HFCP differ from broken conductor protection in UR relays?

Yujie: The operating principle of the I2/I1 method in UR relays is based on sequence currents, whereas HFCP operates based on the ICR.

The I2/I1 method requires a drop of approximately 50% of the load for a successful detection, while HFCP can detect events with less than a 50% reduction in load. The I2/I1 method has also been shown to be insecure for radial networks, as upstream faults could lead to a significant reduction in phase current on a given phase and lead to mis-operation.

HFCP has considerable advantages in terms of security and sensitivity based on its adaptive setpoint and the ability to improve coverage by adding additional PMUs and coordinating between these devices without affecting security, which is not possible with the I2/I1 method.

How does HFCP differ from sensitive earth fault (SEF) protection?

Hasan: SEF protection works by measuring the residual current across the three phases in a system. In ideal conditions, the residual current is zero, but in the event of a fault, the residual current will not be zero as the current from the faulted phase flows through the earth.

SEF can detect events only after a fault condition has occurred, whereas HFCP can detect events prior to the conductor touching the ground and avoid a fault condition from developing. Like Yujie said, Hi-Z, SEF and HFCP are complementary technologies.

How does HFCP differ from rapid earth fault current limiter (REFCL)?

Yujie: REFCL is one of the fire prevention methods that limits the electrical energy released during the earth fault by connecting arc suppression coils and fault current limiters for phase to earth fault. It operates after a fault condition has occurred, whereas HFCP operates before the conductor reaches the ground.

Can HFCP be applied to different grounded/ungrounded systems?

Hasan: HFCP operates by calculating the ICR from load current and voltage measurements, and as a result, the system grounding has no effect on the HFCP solution.

How do DERs affect HFCP?

Yujie: HFCP is designed to work on networks with a high penetration of DERs as their effect is considered in the ICR. A high penetration of DERs may reduce the sensitivity of the solution in some cases, however this can be mitigated by adding additional PMUs to the feeder to improve the coverage.

What about load current? How does it affect HFCP?

Hasan: There is a minimum load current required for HFCP and it can operate effectively in low-load conditions. The setpoint/threshold for the ICR in the HFCP logic is adaptively adjusted based on the feeder loading (current). As the feeder load reduces, a higher ICR is utilized to correctly detect a broken conductor condition.

How does topology of the system affect HFCP?

Yujie: HFCP is designed to work in a variety of different system topologies. However, the topology of the system is a major consideration in terms of how many PMUs are required and where they should be placed on the feeder to optimize HFCP coverage.

How does HFCP behave during lightning strikes?

Hasan: Transient phenomena like lightning strikes do not impact HFCP operation. PMUs send out the phasor measurements and filters out of the high-frequency components of the voltage and current. Moreover, the operating time of the solution is long enough for any lightning-induced currents and voltage to dissipate.

Interesting! Can the system detect contact with tree branches?

Hasan: HFCP is designed to detect open phase conditions, so it is not suited to detect this type of event. Hi-Z protection would be more suitable in this case.

Would HFCP work for covered overhead conductors? Does the type of conductor affect HFCP?

Yujie: Yes, HFCP works for covered overhead conductors.

There is no effect on the HFCP solution based on the type of conductor or its line parameters if an open phase condition occurs and a significant impedance change can be observed. The performance of HFCP is adversely affected for feeders with bundled conductors where only one conductor breaks.

If the conductor falls without any considerable arcing, will the protection be able to detect the fault?

Hasan: The presence of arcing does not adversely affect the HFCP solution and a falling conductor can still be detected within the required time.

HFCP can be implemented for transmission and distribution networks with two different techniques. In transmission networks, HFCP operates by calculating the ICR of the line impedance and requires measurements on all terminals of the line. In distribution networks the ICR of the load impedance is used for detection and a minimum of one PMU at the feeder head is required, while more PMUs can be added to improve the coverage.

How does harmonic content affect the algorithm? Will higher THD make the HFCP less effective or accurate?

Yujie: Harmonic content does not affect the HFCP operation as harmonic components are filtered by PMUs, and the calculation of the ICR depends on fundamental components.

Does HFCP depend on circuit breaker performance?

Yujie: The total operating time of HFCP depends on the network latency, the time to detect the falling conductor, and the breaker operating time.

Hasan: The HFCP solution detects the broken conductor within 500 ms. Considering the minimum clearance for an 11kV voltage level or higher is around 5.6m or 18 feet, a falling time of 1.06 seconds is estimated. That results in about 400 ms of network latency that can be accommodated for communication of measurements and trip signals which should be more than enough for typical substation communication and field area networks.

Does the implementation change between transmission and distribution?

Hasan: Yes, two different techniques are used between transmission and distribution networks. In transmission networks, HFCP operates by calculating the ICR of the line impedance and requires measurements on all terminals of the line. In distribution networks, the ICR of the load impedance is used for detection and a minimum of one PMU is required, while more PMUs can be added to improve coverage.

How does HFCP coordinate with downstream devices?

Hasan: If multiple PMUs are installed on a feeder, a time delay can be configured for the PMU at the substation. The downstream PMUs can be configured to trip their own respective breakers or the breaker at the substation. If a falling conductor is detected by a downstream PMU and cleared within the configured time, the PMU at the substation will not trip the breaker. Furthermore, if the downstream devices detect a loss of voltage condition on one phase, the upstream PMU will trip the breaker immediately.

Is the coordination time of 300ms at the substation fixed or dynamic?

Yujie: The time delay is adjustable. The default value is set to 300ms.

Could there be a physical switch to enable/disable HFCP in the GE Power Gateway (GPG)?

Hasan: The GPG does not have I/O capabilities to enable/disable HFCP. However, a separate I/O device can be used to communicate with the GPG for enable /disable HFCP. The GPG can also communicate with utility's SCADA for remote control.

For what conditions would HFCP be blocked? Could a single pole trip be falsely considered a broken falling conductor?

Yujie: The HFCP operation is blocked internally for a ground fault condition, and a single pole trip due to a fault would not cause a mis-operation.

To avoid mis-operation for a manual operated single pole trip, a blocking signal can be considered.

How easy is it to set the HFCP?

Hasan: Configuration of HFCP is simplified using the HFCP configurator software that allows the engineer to configure the parameters for each PMU and feeder using an easy-to-use graphical user interface. Each field required in the configuration has an associated tooltip that displays explanatory text for each field, and default values are specified as well.

Are there any limitations of HFCP?

Yujie: The coverage of the HFCP solution is dependent on system topology, load distribution and profile, and number of PMUs. There is currently no method available that can cover 100% of branches, but significant coverage can be achieved.

Hasan: I'll also add that HFCP may not be able to detect falling conductors during low load conditions, and the sensitivity of the solution may be reduced in networks with a high penetration of DER. This can be mitigated by installing additional PMUs on the feeder to increase coverage.

AT A GLANCE

HFCP has many benefits. It's easy to configure and provides a significant base coverage with just one PMU at the substation, and coverage can be improved systematically by installing additional PMUs. Other methods require many devices to be installed to provide similar coverage, resulting in increased capital and maintenance costs. Stay tuned for Part 2 of this interview series, where we explore the system architecture of HFCP as well as testing and commissioning of an HFCP solution.

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