Fast Communication-Based Protection and Isolation Schemes

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Abstract—**Traditional TCC-based distribution protection without communications can be slow to operate, especially for faults closer to the source. Furthermore, the number of protective devices that can be placed on a feeder is limited because of the tolerance of their TCC curves. This limits the segmentation capabilities when a fault happens. Many modern relays and feeder protection devices are equipped with communication capabilities. The communication capabilities can be utilized to speed up the operations of the protection devices, as well as provide better segmentations should faults occur. There already exist some communication-based protection schemes and some have been applied in the industry. In this work, we present two novel communication-based schemes: a communication-based permissive protection scheme, and an impedance-based protection scheme that can differentiate between feeder faults and lateral faults. Most communication-based protection schemes, including the existing ones and the new ones in this work, provide unlimited segmentation capabilities. The new schemes presented in this work provide even faster protection than existing communication-based protection schemes. In addition to the fast protection schemes in this work, we also propose a corresponding fast isolation scheme based on communications. An isolation scheme is a mechanism that happens after protection to open the protective devices downstream and closest to the fault. This is to prevent any alternative source downstream of the fault from being reconnected to the fault and reigniting it in an effort to restore some loads downstream of the fault. The proposed communication-based isolation scheme can be used together with the proposed communication-based protection schemes, as well as other existing protection schemes.**

Keywords—distribution protection; power system; communication

I. INTRODUCTION

Traditional Time Current Characteristic- or TCC-based coordination [1][2], has been widely used for the protection of distribution feeders. Its purpose is that only the protection device immediately upstream of a fault, be it a fuse, recloser, or circuit breaker, operates and interrupts the fault current. If achievable, it provides maximum segmentation, thereby minimizing the number of customers experiencing an outage. The principle that TCC-based coordination is based upon is that each protective device waits until all the protective devices downstream can operate for a fault. If none of them operates by the time they are supposed to operate, which is a function of the fault current, it means the fault is within the zone of the protective device in question, and it is allowed to operate. This scheme requires no communication, and can be implemented using simple devices such as fuses, as well as more advanced devices such as mechanical or digital relays.

While widely used, TCC-based coordination does have some drawbacks. First, it requires finding and configuring a different TCC for each device, which takes time and effort. Second, only a limited number of curves can fit between the curve of the distribution transformer fuse and the curve of the circuit breaker at the substation. This is after considering the tolerances of the relay in measuring the fault current, the operation time of the interrupting devices, and the need to wait for the next zero crossing of the current. And third, the closer a fault is to the substation, the longer it takes to clear this fault because of the need to wait for multiple protective devices in series downstream to operate first. When a transformer is experiencing high through fault currents, the windings are subject to severe mechanical stresses causing winding movement, deformations, and in some cases severe damages [3]. Faster fault interruption has the potential of achieving prolonged transformer life. Electric faults are a known source of wildfires [4], and interrupting them faster can potentially reduce the risk of wildfire. Finally, interrupting faults faster reduces the duration of voltage sags on parallel branches or on adjacent feeders. This may have a significant economic impact on end customers.

Consumer electronics are required to follow the ITIC (formerly CBEMA) curve, which states a ride through capability of only one cycle when voltage drops below 70% of nominal voltage. In actual tests though, personal computers demonstrated ride through capabilities ranging up to 15 cycles (U.S. study) and 120 ms (Japanese study) [5]. Adjustable speed drives that control the speed of induction or synchronous motors can ride through a single-phase voltage sag for up to 160 ms, but trip if the voltage sag persists longer than that [6]. Directly fed induction motors may contribute to a fault induced delayed voltage recovery (FIDVR) that can last for a second or more, and lead to the tripping of undervoltage and overcurrent relays [5]. In addition, the likelihood of motor stalling is a function of the voltage sag duration, increasing two-fold when sag duration changes from three to nine cycles [7]. Lastly, directly fed synchronous motors may lose synchronism and would need to be stopped, if the voltage sag persists for too long [5].

In general, improvement to TCC-based coordination can reduce engineering time, increase segmentation, prolong equipment life, mitigate wildfires, and minimize the effect of voltage sags. Permissive and blocking pilot protection schemes using communications between protective devices have been very effective in transmission grids to achieve a high level of segmentation and fast operation [8]. But these rely on the meshed topology of the transmission grid, and the lack of tapped lines between two terminals. Neither is true for distribution grids, where many protective devices still have no form of communication. Nevertheless, utilities that did deploy communication infrastructures, whether over radio or using fiberoptics cables, have also started employing communication-based distribution protection such as the blocking scheme described in Staszesky et al. [9].

Just as in transmission grids [8], blocking schemes are generally slower than permissive schemes because blocking schemes need to intentional delay operation to account for the slowest possible channel time plus a margin. However, permissive schemes have so far evaded distribution grids because they require relays on the other side of the fault, i.e. downstream of it, to recognize the fault is upstream of them. And in a radial topology, these downstream relays do not see any fault current which is what triggers the permissive signal to be sent in transmission application. A solution to overcome this challenge and achieve a protection permissive scheme in a radial distribution grid is presented in Section II.

While communication infrastructures are quickly expanding to include most main-feeder reclosers, the distribution grid is still expected to have numerous fuses and other non-communicating protective devices for the foreseeable future. For a fuse-blowing operation, this requires modification to the permissive scheme typically used in transmission grids, which is also explained in Section II. This modification, however, can result in longer operation time for main-feeder faults. The main feeder recloser does not know if it is detecting a main feeder fault or a lateral fault, and therefore has to delay its operation until the largest fuse downstream has a chance to operate. The solution presented in Section III allows the recloser to identify whether the fault is on the main feeder or on one of the laterals. With this, the upstream recloser can operate for a main-feeder fault as soon as it receives all permissive signals from downstream reclosers.

In Section IV we use a sample feeder to demonstrate quantitively the improvements made possible by these two protection solutions.

Power restoration following a fault has been implemented by many utilities using smart grid devices. When a fault is interrupted by a protective device, if some customers downstream of the fault are connected to an alternative power source via a normally open device, and fault restoration is configured, it is possible to close the normally open device to restore the power for those customers. Before doing that, it is necessary to open the device downstream of the fault to isolate the fault. This is to prevent the restoration process from closing the alternative source into the fault. A fast communication-based downstream isolation scheme is proposed in Section V.

II. COMMUNICATION-BASED PERMISSIVE PROTECTION SCHEME

The proposed communication-based permissive scheme is an enhancement to communication-based blocking schemes. Traditional TCC coordination schemes are limited in the number of interrupting devices a feeder can have. Moreover, interrupting devices closer to the source need to operate relatively slowly. Communication-based blocking schemes such as the one described below do not have such limitations, but their speed may still be limited by the maximum communication latency of the communication platform. Comparing to blocking schemes, the proposed permissive scheme can operate faster to interrupt fault current, because its speed is decided by the actual time it takes for a message to transmit, rather than maximum possible communication latency.

Communication Enhanced Coordination (CEC) [9] is an example of a communication-based blocking scheme. In CEC, each device has two TCC curves, an initial one and a shifted one. The initial curve is slower than the maximum communication latency, and the shifted curve is slower than the initial curve. The maximum communication latency is defined as the maximum possible time it takes for a message to be received by a device since the start of an event. If the device has not received a message by the end of the maximum communication latency time since the start of an event, it implies that no message was sent to it in the first place. All devices have the same initial curves and the same shifted curves. All devices are on their initial curves during quiet conditions. When a device detects OC, it sends a CEC message to its immediate upstream device. If a device detects OC and receives a CEC message, it shifts its TCC curve to the shifted slower one. Therefore, using CEC, when all CEC messages are sent and received successfully within maximum communication latency time, only the device immediately upstream of the fault trips open.

The basic communication-based permissive protection scheme proposed in this work is explained as follows. Whenever a device detects drop of voltage (DoV) without overcurrent, it sends a DoV message to its immediate upstream device. Whenever a device detects overcurrent (OC), and receives DoV messages from all its immediate downstream devices, it means this device's immediate downstream section is faulted, and it opens immediately to interrupt the fault. The most downstream devices have a special treatment: they open immediately as soon as OC is detected. In communication-based blocking schemes, the wait-time to interrupt a fault is the maximum possible time of one message passing from a fault interrupting device to another, plus the maximum response time of the downstream protection plus a buffer time (safety margin). In the proposed permissive scheme, the wait-time to interrupt a fault is the actual time of one message passing from a downstream device to the fault interrupting device, when a fault happens in its immediate downstream section. Therefore, the proposed permissive scheme is faster than communication-based blocking schemes.

In the proposed permissive scheme, extra time can be added before opening for all devices that use this scheme to accommodate further downstream non-communicating devices that use traditional TCC coordination such as lateral fuses. Specifically, a communicating device A decides there is a fault immediately downstream of it, i.e. all other communicating

devices, if any, are downstream of this fault. Assume that device B is a non-communicating device downstream of device A. If A's decision is made before B operates on B's own curve, A waits until B's maximum time to operate, and only trips open if device B does not clear the fault at this point. If A makes its decision to open after the time device B needs to operate on B's own curve, A trips open immediately.
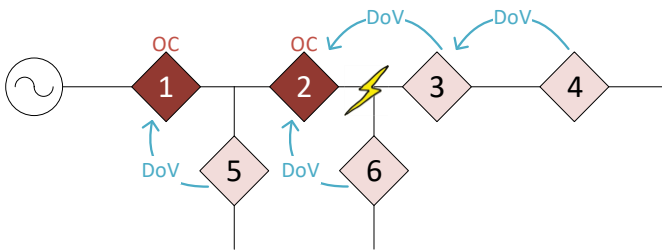

Fig. 1. An example feeder illustrating basic communication-based permissive protection. Devices in dark red detect overcurrent; devices in light red detect drop of voltage.

In the example in Fig. 1, Device #2 knows its immediate downstream section is faulted as soon as it detects OC and receives DoV messages from Devices #3 and #6, and opens to interrupt the fault as soon as possible. The process takes one message passing time from the device(s) immediately downstream of the fault to the device immediately upstream of the fault, regardless of the location of the devices on the feeder. Note that Device #1 does not open, because it only receives a DoV message from Device #5, but not from Device #2. In other words, Device #1 does not receive DoV messages from all its immediate downstream devices.

A protection scheme is considered reliable, if it guarantees that at least one device upstream of a fault operates to clear the fault (not necessarily in a coordinated fashion), when any message packet is dropped during the protection (for communication-based protection schemes), or any single device participating the scheme malfunctions and does not operate as instructed.

TCC coordination is an example of a reliable protection scheme. It does not rely on communications. If any device does not operate on a fault as expected due to malfunction, another device upstream of this device operates to clear the fault.

Communication Enhanced Coordination (CEC) is also a reliable protection scheme. Consider two cases. First, if a message packet is lost during a fault, a device upstream but not immediately upstream of the fault does not shift its TCC curve to a slower curve, and may trip open unnecessarily. Second, if no message is lost, but the device immediately upstream of the fault does not trip open due to malfunction, another device upstream of this device trips open on its slower shifted curve. In both cases, CEC guarantees that at least one device upstream of the fault trips open to clear the fault.

When used alone, the proposed permissive scheme is not reliable. Specifically, it is possible that no device operates if a single message gets lost. For example, in Fig. 1, if the DoV message from Device #3 to #2 is lost, then Device #2 does not open to interrupt the fault, nor does Device #1. Using the proposed permissive scheme together with another reliable

protection scheme as a backup, the resulting scheme becomes a reliable protection scheme. Specifically, the combined protection scheme runs the permissive scheme and the backup reliable scheme in parallel, and opens the device when either scheme instructs the device to trip open.

When traditional TCC coordination is used as backup for the proposed permissive scheme, the backup TCC coordination of a feeder should be set using the general criteria for TCC coordination. When a fault happens, a device upstream of the fault trips open due to its TCC curve, or the proposed permissive scheme, whichever takes effect first. Similarly, when a blocking scheme such as CEC is used as backup for the proposed permissive scheme, the blocking scheme should be set with its general criteria. When a fault happens, a device upstream of the fault trips open due to the blocking scheme, or the proposed permissive scheme, whichever takes effect first.
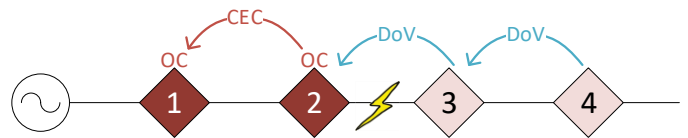

Fig. 2. An example network of permissive scheme using CEC as backup. Devices in dark red detect overcurrent; devices in light red detect drop of voltage.

Note that with the loss of a single message, the combination of CEC and the proposed permissive scheme still remains coordinated. Specifically, when using CEC as backup for the proposed permissive scheme, DoV messages for the proposed permissive scheme, and CEC messages for CEC are both being sent. This is illustrated in the example in Fig. 2. Since the initial CEC curves of the devices are slower than the maximum communication latency, if the DoV message from Device #3 to Device #2 is successfully received by Device #2, then Device #2 trips open before Device #2's initial CEC curve takes effect. If the DoV message from Device #3 to Device #2 is lost, but the CEC messages are successfully transmitted, then Device #2 trips open on its initial CEC curve, and Device #1 does not open because it is on its shifted slower CEC curve due to the CEC message from Device #2 to Device #1. Therefore, the loss of a DoV message may force the system to operate on the backup CEC mechanism. Although slower, the system is still coordinated in this case. On the other hand, if CEC messages are lost during transmission, but DoV messages are transmitted successfully, then the system operates on the proposed permissive scheme as designed. If both DoV messages and CEC messages are lost, then the system will not be coordinated. However, due to the usage of backup CEC mechanism, at least one device upstream of the fault is still guaranteed to trip open, therefore the system is reliable.

Fig. 3 shows an example of TCC curves for the proposed permissive scheme using CEC as backup. The initial and shifted CEC curves are the same in all communication-enabled reclosers. The fuse clearing curve is for the largest lateral fuse installed on the feeder. The initial CEC curve is truncated by the maximum communication latency, because it needs to be slower than the maximum possible time for one message passing from a fault interrupting device to another. The proposed permissive scheme operates between the fuse clearing time and the initial

CEC curve (the green area in Fig. 3). The operating time of the permissive scheme is the actual communication time per instance, or the fuse clearing time, whichever is greater.
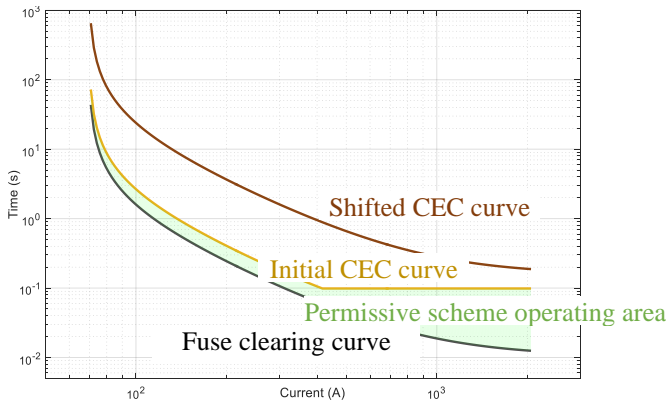

Fig. 3. An example network of permissive scheme using CEC as backup. Devices in dark red detect overcurrent; devices in light red detect drop of voltage.

III. IMPEDANCE-BASED PROTECTION SCHEME

With traditional TCC-based protection coordination, a protective device needs to wait for all downstream devices to potentially operate before it can operate itself. This provides the desired segmentation, at the expense of slower clearing time. The one exception to this is that the upstream device can tell the fault must be within its zone of protection, if the fault current is above the available short-circuit current of each of the downstream devices. In this case, the upstream device can operate instantaneously. But many in-zone faults may not pass this criterion. One, a downstream protective device, such as a lateral fuse, may be located very close to the upstream device, so almost any in-zone (main-feeder) fault would have fault current below the available short-circuit current for that lateral fuse. Two, the fault may not be a bolted fault, with some resistance between the phase and the neutral / ground for a single-line-to-ground fault, or between the phases for a phase-to-phase fault. This may reduce the fault current below the available short-circuit current of the next downstream device. The latter can be potentially mitigated if one replaces the fault current magnitude with the apparent fault reactance, as measured by the upstream device, to distinguish between in-zone and out-of-zone faults.

The permissive scheme described in Section II allows downstream devices to indicate the fault is not within their zone, providing faster response time without sacrificing segmentation. But it requires those downstream devices to be able to communicate, fast, with the upstream device. However, most lateral segments in the distribution network are still protected by fuses today, which have no ability to communicate. Even with electronics lateral reclosers, establishing such fast communication framework which includes every lateral recloser, could be prohibitively expensive. Note that this does not preclude the benefits of the permissive scheme. The clearing time in that scheme is limited by the slowest non-communicative device. A (non-communicating) lateral fuse very often operates faster than the next downstream feeder recloser. This is because that lateral fuse only needs to coordinate with the distribution

transformers' fuses, inrush current, and in some cases, another mid-lateral fuse. In contrast, a feeder recloser needs to coordinate with multiple downstream reclosers in series, and the lateral and distribution transformers further downstream. Therefore, the permissive scheme, by having to coordinate only with the lateral fuses, but not with the communicating downstream reclosers, can achieve significant improvement in fault clearing time.

The scheme in this section allows an upstream protective device to determine, with high likelihood, whether a fault is on the main feeder between itself and the next communicating feeder protective device, or downstream of one of the (non-communicating) lateral protective devices, which are most commonly fuses. If the fault is indeed on the main feeder, the upstream protective device can operate very fast, not having to coordinate with the lateral protective devices that are not going to interrupt this fault. We should qualify that under this scheme, it is possible for some close-in faults just downstream of the lateral devices to be mistaken for feeder faults. This may result in more customers losing power than with traditional coordination. However, such close-in faults, assuming the probability of a fault on a line segment is proportional to its length, cover a very small portion of faults expected on the feeder. The impact should therefore be minimal. In the past and today, minimizing fault clearing time has been a secondary objective to segmentation. What we are proposing here is to assign higher priority to minimizing fault clearing time, at the expense of a slight decrease in segmentation performance.

Reactance-based fault location operates under the assumption that the fault is purely resistive, but does not require it to be a bolted fault. It is also independent of the source impedance. During a single-line-to-ground (SLG) fault on phase a for example, the complex voltage V_a seen by an upstream device is:

$$V_a = \left(Z_{aa}d + R_f\right)I_a$$

where Z_{aa} is the self-impedance of phase a per unit distance of the overhead line or underground cable, d is the distance to the fault, R_f is the fault resistance, and I_a is the complex current seen by the upstream device. Simple algebra leads to:

$$d = \Im\frac{V_a}{I_a}\Big/ X_{aa}$$

where $\Im$ stands for the imaginary part, and X_{aa} is the reactance part of the self-impedance of phase a. The same principle, but with different equations, can be used for a phase-to-phase fault. This method can be made even more accurate by considering the mutual impedance and the current flowing through the other phases. This may be necessary if the fault current is only a few multiples of the load current.

Laterals typically have different line impedance than the main feeder due to the smaller diameter of the conductors, and the smaller spacing between the conductors and/or ground. If only the main feeder reactance is used, the distance to the fault may be off for lateral faults. However, since the objective here is not to locate the fault, but only to discriminate between lateral

faults and main feeder faults, using only the main feeder reactance is sufficient.

While this method can estimate the distance to the fault, it is not sufficient to determine if the fault is on the main feeder or on a lateral. This can be seen by comparing the lateral fault and the main-feeder fault in Fig. 4 and Fig. 5, respectively. Both faults register the same distance from the upstream relay. To address this, we introduce the distance d_1, which measures the length of the main feeder section starting from the upstream device that carries the fault current. In the case of the lateral fault (Fig. 4), it is the distance between the upstream relay and the lateral fuse. In the case of the main feeder fault (Fig. 5), it is the distance between the upstream relay and the fault. The voltage seen by the downstream relay, V_a', is then

$$V_a' = V_a - Z_{aa}d_1I_a,$$

from which the least-square estimation for d_1 becomes

$$d_1 = \Re\frac{V_a - V_a'}{Z_{aa}I_a}.$$

If the calculation matches, i.e. $d_1 \approx d$, then we can determine it is a feeder fault. Otherwise, if $d_1 < d$, we can determine it is a lateral fault. In practice, the downstream relay transmits the voltage it sees in a DoV message to the upstream relay as soon as it observes a drop of voltage according to Section II. The upstream device then computes d based on its own measurements and estimates d_1 using its own measurements and the data it receives from the downstream relay.
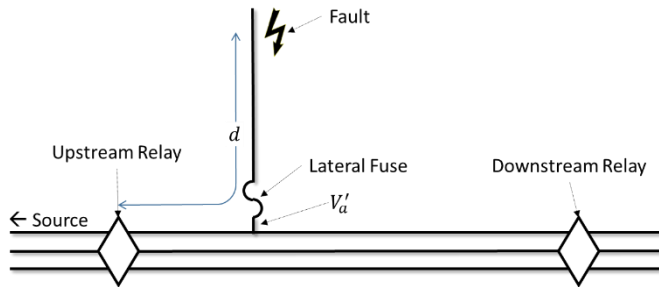

Fig. 4. A lateral fault. d is the distance to the fault as computed by the upstream relay. V_a' is the voltage seen by the downstream relay.
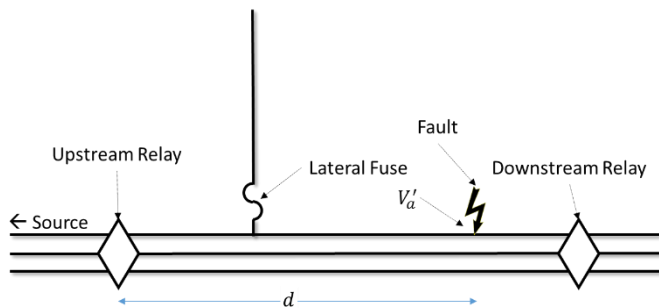

Fig. 5. A main feeder fault. d is the distance to the fault as computed by the upstream relay, which is the same as in Fig. 4. V_a' is the voltage seen by the downstream relay, which is different than what the downstream relays sees in Fig. 4.

In case the feeder branches and there are multiple reclosers immediately downstream of the upstream relay, and none of them reports the fault is further downstream, the upstream relay collects the voltage readings from each of them. It then calculates a d_1 separately for each downstream relay, as well as a single fault distance d using its own measurements. If any of the d_1's equals d, the fault is determined to be a main-feeder fault. Otherwise, it is a lateral fuse fault.
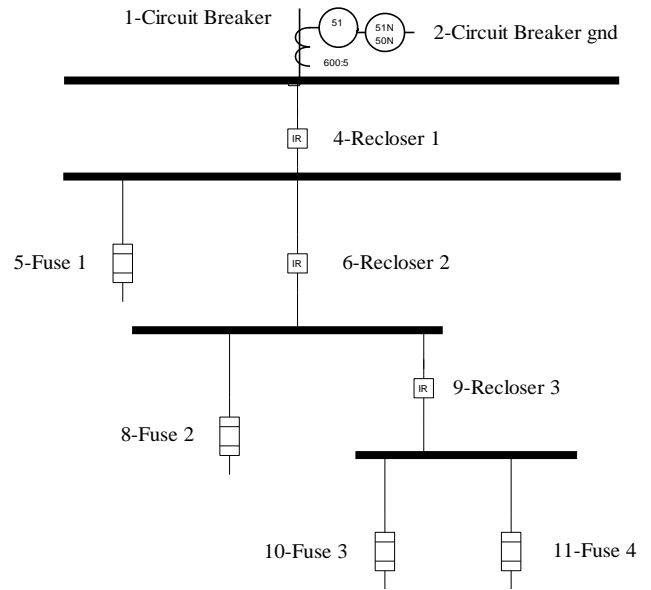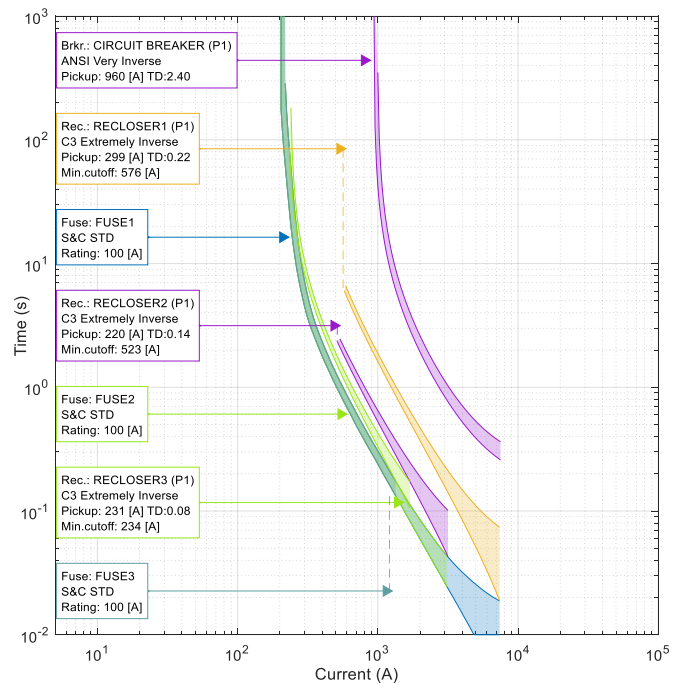

Fig. 6. A one-line diagram of the circuit.

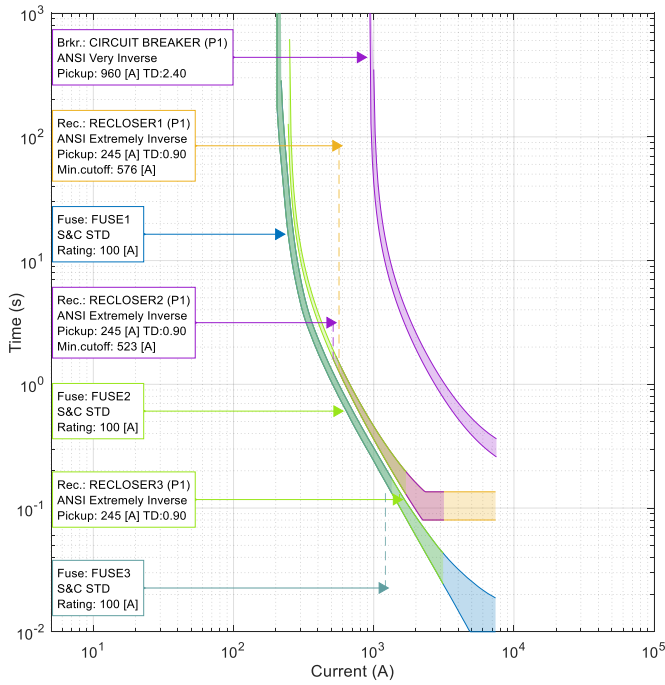Fig. 7. Coordination using conventional TCC curves.

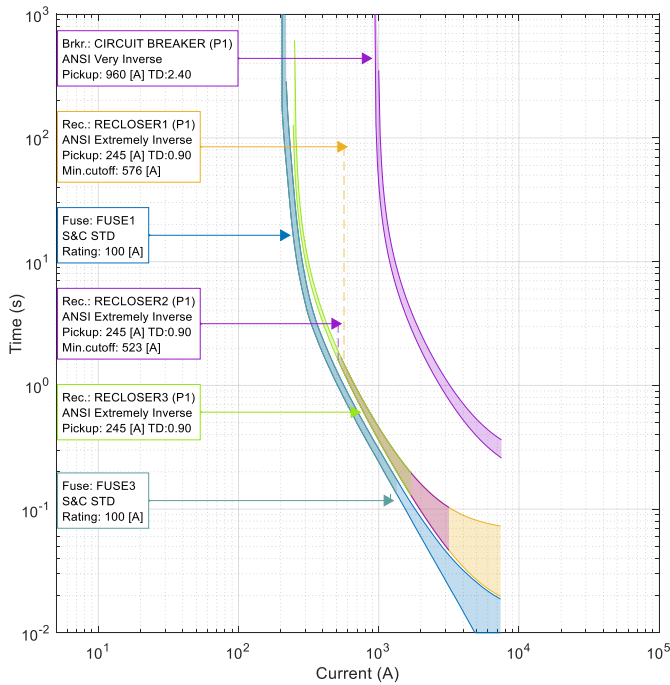Fig. 8. Coordination using a blocking scheme.

Fig. 9. Coordination using a permissive scheme.

IV. EVALUATION

To evaluate the performance of the proposed coordination methods in Section II and Section III, the speed of operation for two different fault scenarios are evaluated and compared with conventional TCC-based coordination and a blocking scheme.

The one-line diagram of the system under study is shown in Fig. 6. TCC-based coordination for the fuses, the reclosers, and the circuit breaker is shown in Fig. 7.

In case 1, the fault is applied between Reclosers 1 and 2 and the fault current is 4000 A. In this case, the operation time based on TCC coordination is captured by the maximum operating time of the orange curve in Fig. 7 at I = 4000 A, which is 149 ms. In case 2, the fault is applied between Reclosers 2 and 3 and the fault current is 2000 A. In this case, the operation time based on TCC coordination is captured by the maximum operating time of the TCC curve for Recloser 2 (purple curve) in Fig. 7 at I = 2000 A, which is 190 ms.

For communication-based coordination schemes such as blocking schemes and the permissive scheme, all reclosers may share the same TCC curve with different minimum cutoffs. In this paper, the maximum expected communication latency is assumed to be 80 ms, and the actual latency is assumed to be 40 ms. Fig. 8 and Fig. 9 illustrate the coordination curves for the blocking scheme and the permissive scheme respectively. For the blocking scheme, the minimum trip time of the reclosers is about 80 ms. This means that a recloser needs to wait for at least 80 ms (communication latency) to trigger the opening command after it detects a fault. The waiting time can be longer if the maximum clearing time of the lateral fuse is longer than 80 ms. In contrast, for the permissive approach, the minimum waiting time before operation is 40 ms. Again, the waiting time can be longer because of the lateral fuse. For the impedance-based method, for these two main-feeder faults, the upstream recloser does not wait for the fuse to operate first and initiate the trip command 40 ms after the detection of the fault. Instead, it issues the trip command as soon as it determines that the fault is immediately downstream of it on the main feeder.
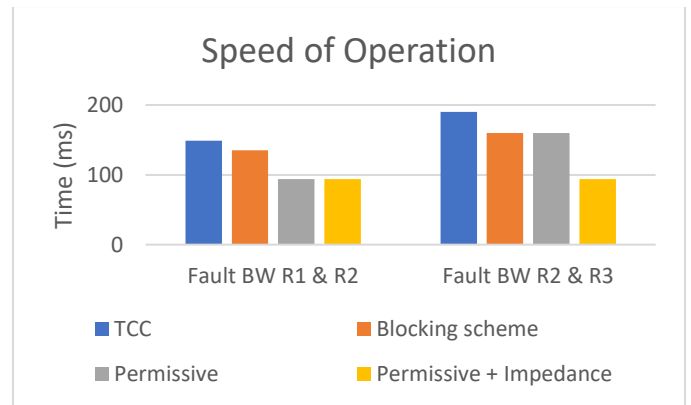

Fig. 10. Speed of operation for TCC, blocking scheme, permissive scheme, and permissive + impedance coordination for two case studies (a. fault between R1 & R2 with fault current 4000 A, b. Fault between R2 & R3 with fault current 2000 A).

Fig. 10 compares the maximum clearing time, including detection time, tolerances, and interrupting time, of all mentioned methods in this paper. Clearly, the proposed permissive scheme and impedance-based scheme outperform the existing TCC coordination and existing blocking scheme in terms of the operation speed of feeder faults. Moreover, when the fault is between Reclosers 2 and 3, the impedance-based

protection scheme combined with the permissive scheme outperforms the permissive scheme alone. This is because the protective device makes the fast determination that the fault is on the main feeder, and operates immediately without waiting for any non-communicating downstream lateral fuse to operate first.

For the communication-based downstream isolation scheme, its speed is dependent on the speed of the protection scheme being used. The time it takes a device downstream of a fault to open and isolate the fault is the maximum of the time of the upstream protection and the time it takes the OC message from the upstream device to be received by the downstream device.

V. COMMUNICATION-BASED DOWNSTREAM ISOLATION SCHEME

After a fault is interrupted by an upstream protective device, it is possible that the customers downstream of the fault are connected to an alternative power source through a normally open device. In this case, it is desirable to close the normally open device to restore the power of some customers downstream of the fault from the alternative source. However, before closing the normally open device, to prevent the alternative source from being closed into the fault, the device immediately downstream of the fault should open to isolate the fault.

The proposed communication-based downstream isolation scheme works as follows. Whenever a device detects overcurrent (OC), it sends an OC message to all its immediate downstream devices. If both of the following have happened to a device, it means the device is immediately downstream of the faulted section: 1. It detects complete loss of voltage (LoV), which means a device upstream of it has opened to interrupt the fault; 2. It receives an OC message from its immediate upstream device. If both are true, the device opens to isolate the fault for its downstream section. The most upstream device in a feeder opens immediately to isolate the fault as soon as LoV is detected, without waiting for an OC message to arrive. The time it takes to isolate is the maximum between the latency of one message passing, and the fault clearing time (including any intentional delays to maintain coordination).
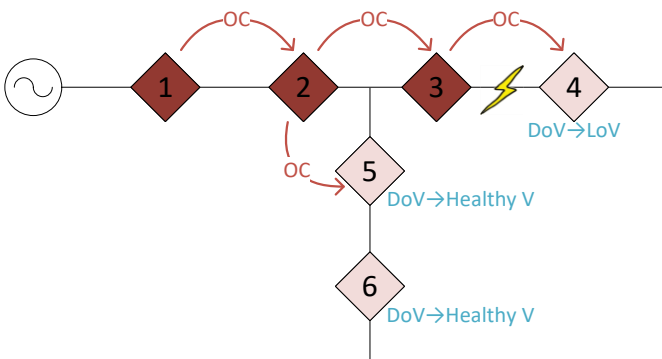

Fig. 11. An example feeder illustrating communication-based downstream isolation. Devices in dark red detect overcurrent; devices in light red detect drop of voltage.

In the example in Fig. 11, Device #4 knows its immediate upstream section is faulted after it detects LoV, and it receives an OC message from Device #3. Therefore Device #4 opens to isolate the fault. Device #5 does not mistakenly decide that its immediate upstream section is faulted, because it initially detects drop of voltage (DoV), but then healthy voltage returns after DoV after Device #3 interrupts the fault.
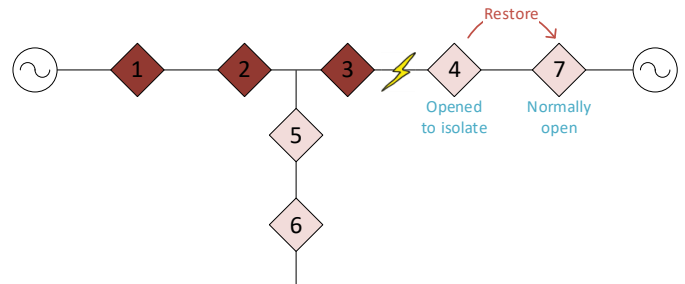

Fig. 12. An example feeder illustrating restoration after downstream isolation. Device #4 opens due to isolation logic, sends a restoration request message to normally open Device #7. Device #7 receives the restoration message and closes to restore the load between Device #4 and Device #7.

When a device opens for isolation, it sends a restoration request message to a designated normally open device if there is one. When a normally open device receives a restoration request message from an isolating device, it closes to restore the load downstream of the fault. Fig. 12 shows an example of restoration that happens after isolation.

In traditional isolation schemes, the device upstream of the fault needs to wait until it determines the location of the fault and clears the fault before it sends a message to the device downstream of the fault to isolate. In our scheme, the message to isolate is sent as soon as the fault is detected and before it is even located, saving the extra message latency time after the fault is already cleared.

VI. CONCLUSION

In this paper, two communication-based protection schemes for distribution feeder protection are proposed: a communication-based permissive protection scheme, and an impedance-based protection scheme. Both schemes use communication to coordinate the protection of a feeder. A corresponding fast isolation scheme based on communications is also proposed in this paper. It can be used together with the proposed communication-based protection schemes, as well as other existing protection schemes. The time it takes to isolate with our communication-based isolation scheme is the maximum between the latency of one message passing, and the fault clearing time.

The communication-based permissive scheme uses the devices' measurements and messaging between the devices to locate the closest upstream communicating device of the fault, and makes that device open as fast as possible, given that enough time is waited for the downstream non-communicating devices to operate such as lateral fuses. Therefore, the speed of the permissive scheme is dependent on the actual messaging time

and the operating speed of the downstream non-communicating devices.

The impedance-based permissive protection scheme uses the devices' measurements, the prior knowledge about the line impedance, and communications between the devices to determine if the fault is immediately downstream of a communicating device, and if it is on the lateral or on the main feeder. If the fault is determined to be on the lateral, the feeder device allows the lateral fuse to clear the fault first. If the fault is determined to be on the main feeder, the feeder device opens to clear the fault immediately without having to wait for any lateral fuse to operate first.

As demonstrated by quantitative evaluation, both protection schemes provide faster distribution feeder protection than existing protection schemes.

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BIOGRAPHIES

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Yoav Sharon is the manager of the Power System Control Group in the Technology and Breakthrough Innovation Department at S&C Electric Company. He is responsible for developing protection, automation, and data analytics solutions for the distribution grid. He earned his Ph.D. in Electrical and Computer Engineering from University of Illinois at Urbana-Champaign. He is a licensed Professional Engineer in the state of Texas, and a Senior Member of the IEEE. For his work in the power system field, he was granted 10 U.S. patents.