IMPROVED COMMUNICATION-BASED PROTECTION SCHEMES

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CONTENTS

SUMMARY

Traditional time-current characteristic (TCC)-based distribution protection without communications can be slow to operate, especially for faults closer to the source. Furthermore, the number of protection 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 used to speed up the operations of the protection devices as well as provide better segmentations should faults occur. Some communication-based protection schemes already exist, 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.

INTRODUCTION

Traditional 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 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 it 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 has 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 damage[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 Information Technology Industry Council (ITIC) (formerly Computer Business Equipment Manufacturers Association [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

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[1] J. L. Blackburn, T. J. Domin, *Protective Relaying: Principles and Applications*, 4th Edition, CRC Press, 2014

[2] S. H. Horowitz, A. G. Phadke, J. K. Niemira, *Power System Relaying*, 4th Edition, Wiley, 2014

[3] A. E. B. Abu-Elanien, M. M. A. Salama, "Asset management techniques for transformers" (Electric Power Systems Research 80, 2010, pages 456-464)

[4] California Department of Forestry & Fire Protection, "2020 Wildfire Activity Statistics", Online: https://www.fire.ca.gov/media/0fdfj2h1/2020_redbook_final.pdf

[5] M. H. J. Bollen, *Understanding Power Quality Problems – Voltage Sags and Interruptions*, IEEE Press, 1999

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[7]. 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[8]. Lastly, directly fed synchronous motors may lose synchronism and would need to be stopped if the voltage sag persists for too long[9].

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[10]. 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 fiber-optic cables, have also started using communication-based distribution protection, such as the blocking scheme described in Staszesky et al.[11].

Just as in transmission grids[12], blocking schemes are generally slower than permissive schemes because blocking schemes need to intentionally 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 the "Communication-Based Permissive Protection Scheme" section on page 4.

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 the "Communication-Based Permissive Protection Scheme" section on page 4. This modification, however, can result in longer operation time for main-feeder faults. The main feeder recloser does not know whether 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 the "Impedance-Based Protection Scheme" section

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[6] S. Ž. Djokic et al, "Sensitivity of AC Adjustable Speed Drives to Voltage Sags and Short Interruptions" (IEEE Trans. Power Delivery, Vol. 20, No. 1, 2005, pages 494-505)

[7] M. H. J. Bollen

[8] K. G. Ravikumar et al, "Analysis of fault-Induced delayed voltage recovery using EMTP simulations" (2016 IEEE/PES Transmission and Distribution Conference and Exposition)

[9] M. H. J. Bollen

[10] B. Kasztenny et al, "Permissive or blocking pilot protection schemes? How to have it both ways" (74th Annual Conference for Protective Relay Engineers, 2021)

[11] D. M. Staszesky, R. P. O'Leary, T. J. Tobin, "Fault protection system and method for an electrical power distribution system" (U.S. Patent 10,418,804 B2, 2019)

[12] B. Kasztenny et al

on page 7 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 the "Evaluation" section on page 9, we use a sample feeder to demonstrate quantitatively the improvements made possible by these two solutions.

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. Compared with 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 instead of maximum possible communication latency.

Communication-enhanced coordination (CEC)[13] 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 overcurrent, it sends a CEC message to its immediate upstream device. If a device detects overcurrent and receives a CEC message, it shifts its TCC curve to the shifted slower one. Therefore, when 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 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 overcurrent 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

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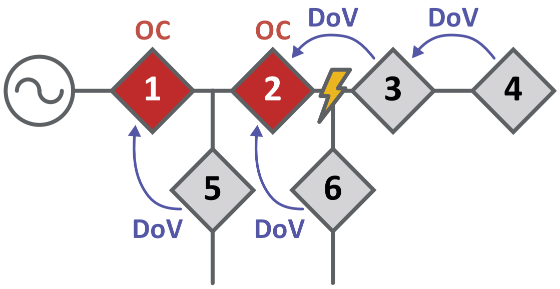
[13] D. M. Staszesky

downstream non-communicating devices that use traditional TCC coordination, such as lateral fuses. Specifically, 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 Device B is a non-communicating device downstream of Device A. If Device A's decision is made before Device B operates on Device B's own curve, Device A waits until Device B's maximum time to operate, and it only trips open if Device B does not clear the fault at this point. If Device A makes its decision to open after the time Device B needs to operate on Device B's own curve, Device A trips open immediately.

In the example in **Figure 1**, Device 2 knows its immediate downstream section is faulted as soon as it detects overcurrent and receives DoV messages from Devices 3 and 6, and it 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.

FIGURE 1. An example feeder illustrating basic communication-based permissive protection. Devices in dark red (numbered 1 and 2) detect overcurrent; devices in light gray (numbered 3 through 6) detect drop of voltage.



A protection scheme is considered *reliable* if it guarantees 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 in 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 because of a malfunction, another device upstream of this device operates to clear the fault.

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 it may trip open unnecessarily. Second, if no message is lost but the device immediately upstream of the fault does not trip open because of a malfunction, another device upstream of this device trips open on its slower shifted curve. In both cases, CEC guarantees 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 **Figure 1**, if the DoV message from Device 3 to Device 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 it opens the device when either scheme instructs the device to trip open.

When traditional TCC coordination is used as a 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 because of its TCC curve or the proposed permissive scheme, whichever takes effect first. Similarly, when a blocking scheme such as CEC is used as a 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 because of the blocking scheme or the proposed permissive scheme, whichever takes effect first.

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 a 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 **Figure 2**. Because 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 its 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 because of 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, because of the use of a backup CEC mechanism, at least one device upstream of the fault is still guaranteed to trip open; therefore, the system is reliable.

FIGURE 2. An example network of a permissive scheme using CEC as a backup. Devices in dark red (numbered 1 and 2) detect overcurrent; devices in light gray (numbered 3 and 4) detect drop of voltage (DoV).

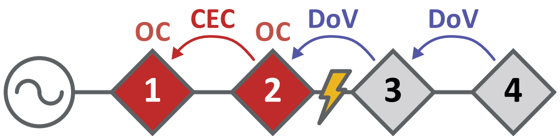
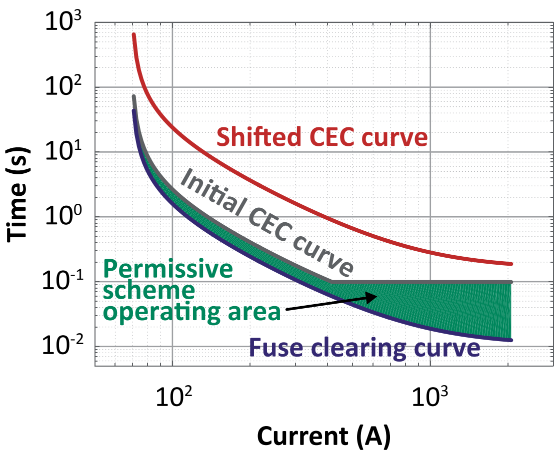


Figure 3 shows an example of TCC curves for the proposed permissive scheme using CEC as backup. The initial and shifted CEC curves are the same in all communication-enabled reclosers. The fuse-clearing curve is for the largest lateral fuse installed on the feeder. The initial CEC curve is truncated by 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 **Figure 3**). The operating time of the permissive scheme is the actual communication time per instance, or the fuse clearing time, whichever is greater.

FIGURE 3. Example curves of a permissive scheme using CEC as a backup.



IMPEDANCE-BASED PROTECTION SCHEME

With traditional TCC-based protection coordination, a protective device must 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 the "Communication-Based Permissive Protection Scheme" section on page 4 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 today are still protected by fuses, which have no ability to communicate. Even with electronic lateral reclosers, establishing such a fast communication framework that 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 must 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 by 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 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:

$$d = \left. \Im \frac{V_a}{I_a} \right/ X_{aa}$$

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 because of 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, because 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 whether 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 **Figure 4** and **Figure 5 on page 9** 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 (**Figure 4**), it is the distance between the upstream relay and the lateral fuse. In the case of the main-feeder fault (**Figure 5 on page 9**), it is the distance between the upstream relay and the fault. The voltage seen by the downstream relay, V_a', is then

$$V_a' = V_a - Z_{aa} d_1 I_a,$$

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 the “Communication-Based Permissive Protection Scheme” section on page 4. 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.

FIGURE 4. A lateral fault where “*d*” is the distance to the fault as computed by the upstream relay and “V_a'” is the voltage seen by the downstream relay.

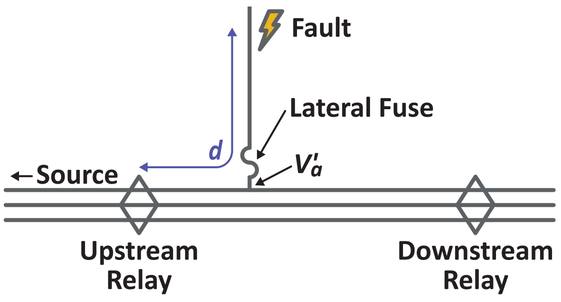
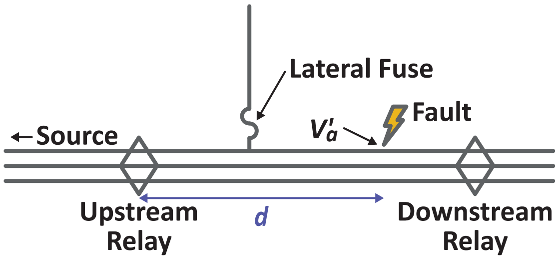
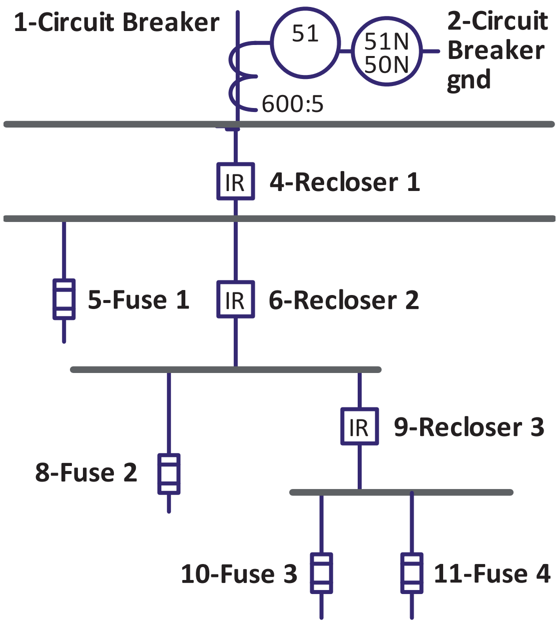


FIGURE 5. A main-feeder fault where “*d*” is the distance to the fault as computed by the upstream relay, which is the same as in **Figure 4 on page 8**. “V_a'” is the voltage seen by the downstream relay, which is different from what the downstream relays see in **Figure 4 on page 8**.



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 fault.

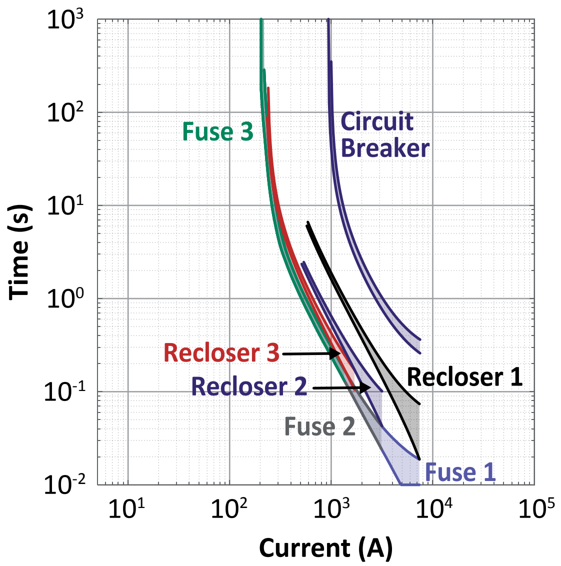
FIGURE 6. A one-line diagram of the circuit.



EVALUATION

To evaluate the performance of the proposed coordination methods in the “Communication-Based Permissive Protection Scheme” section on page 4 and in the “Impedance-Based Protection Scheme” section on page 7, the speed of operation for two different fault scenarios is evaluated and compared with conventional TCC-based coordination and a blocking scheme. The one-line diagram of the system under study is shown in **Figure 6**. TCC-based coordination for the fuses, the reclosers, and the circuit breaker is shown in **Figure 7**.

FIGURE 7. Coordination using conventional TCC curves.



Circuit Breaker (P1)
ANSI Very Inverse
Pickup: 960 [A] TD:2.40

Fuse 2
S&C STD
Rating: 100 [A]

Recloser 1 (P1)
C3 Extremely Inverse
Pickup: 299 [A] TD:0.22
Min.cutoff: 576 [A]

Recloser 3 (P1)
C3 Extremely Inverse
Pickup: 231 [A] TD:0.08
Min. cutoff: 234 [A]

Fuse 1
S&C STD
Rating: 100 [A]

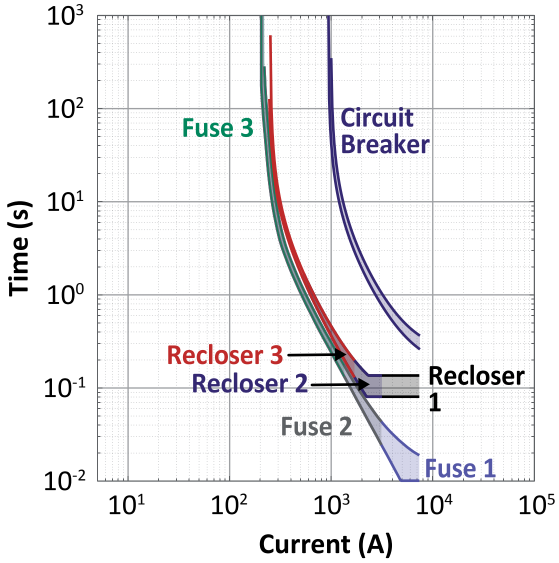
Fuse 3
S&C STD
Rating: 100 [A]

Recloser 2 (P1)
C3 Extremely Inverse
Pickup: 220 [A] TD:0.14
Min.cutoff: 523 [A]

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 curve of Recloser 1 in **Figure 7 on page 9** 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 in **Figure 7 on page 9** 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. **Figure 8** and **Figure 9 on page 11** 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 a recloser must 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 the fault is immediately downstream of it on the main feeder.

FIGURE 8. Coordination using a blocking scheme.



Circuit Breaker (P1)
ANSI Very Inverse
Pickup: 960 [A] TD:2.40

Recloser 1 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90
Min.cutoff: 576 [A]

Fuse 1
S&C STD
Rating: 100 [A]

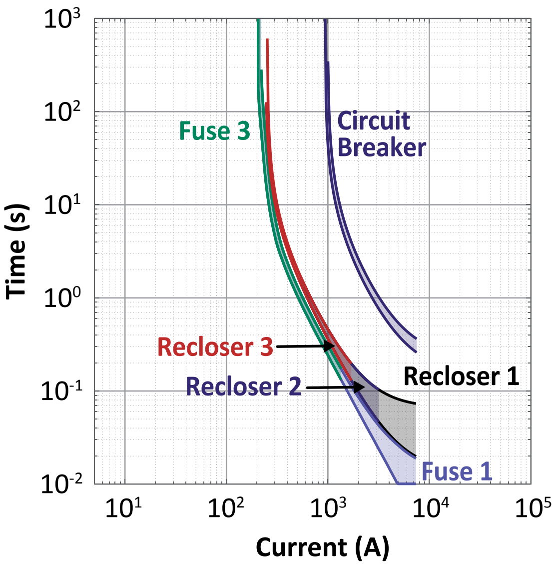
Recloser 2 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90
Min.cutoff: 523 [A]

Fuse 2
S&C STD
Rating: 100 [A]

Recloser 3 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90

Fuse 3
S&C STD
Rating: 100 [A]

FIGURE 9. Coordination using a permissive scheme.



Circuit Breaker (P1)
ANSI Very Inverse
Pickup: 960 [A] TD:2.40

Recloser 1 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90
Min.cutoff: 576 [A]

Fuse 1
S&C STD
Rating: 100 [A]

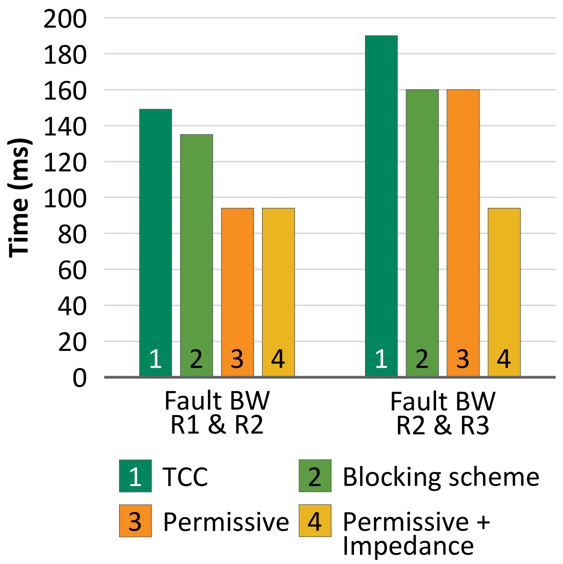
Recloser 2 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90
Min.cutoff: 523 [A]

Recloser 3 (P1)
ANSI Extremely Inverse
Pickup: 245 [A] TD:0.90

Fuse 3
S&C STD
Rating: 100 [A]

Figure 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 the fault is on the main feeder and operates immediately without waiting for any non-communicating downstream lateral fuse to operate first.

FIGURE 10. Speed of operation for TCC, blocking scheme, permissive scheme, and permissive + impedance coordination for two case studies (where a fault between R1 and R2 with fault current at 4000 A and where a fault is between R2 and R3 with fault current at 2000 A).



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.

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 it 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 whether the fault is immediately downstream of a communicating device and whether 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 do existing protection schemes.

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