Adaptive Coordination Schemes to Reduce Fault Energy in Distribution Feeders Using Wireless Protection Sensors

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Why should we care about fault energy?

- Fault current can result in equipment damage and poses a danger to the public and environment
- Traditional distribution protection systems sacrifice speed for selectivity
- Slow-acting protection schemes result in higher fault energy, especially problematic in areas with a high fire risk
- Why not speed up protection?

Fault energy
Easy comparison

- Apply current (I) across resistance (R) for time (T), and energy is expressed as

  $E = I^2RT$

- We see that energy is most sensitive to current, but fault current is not easily controlled
- We assume (R) = 1, leaving time (T) as the variable
- We now have a unitless quantity for comparison purposes, expressed as

  $E_F = I^2T$

Fault energy
Reclose sequence

Example permanent fault with two reclose attempts

$$E_{FT} = I^2T_{F1} + I^2T_{F2} + I^2T_{F3}$$

$$E_{FT} = I^2(T_{F1} + T_{F2} + T_{F3})$$

We call $T_{F1} + T_{F2} + T_{F3}$ the fault “dwell time”

Urban vs. rural distribution feeder generalization

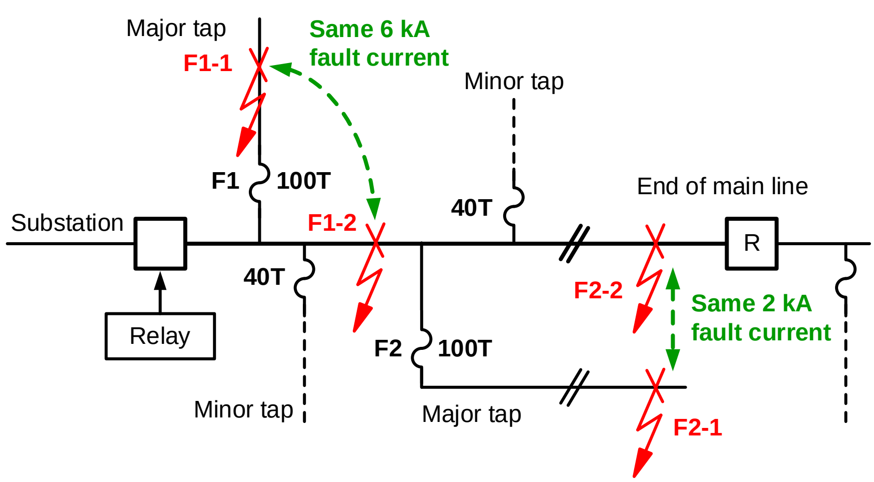
	Urban	Rural
Length	Short	Long
Customer count	High	Low
Trouble isolation and restoration	Aided by automatic or manual tie switches	Purely radial – requires crew visit
Load current	High	Low to moderate
Maximum fault levels	High to moderate	Moderate to low – varies over length
Midline reclosers	Seldom used	Frequently used
Protection strategy	Fuse blowing	Fuse blowing Fuse saving is possible for midline reclosers
Environmental risk	Low	Moderate to high Seasonal and geographical variation

Urban distribution feeder

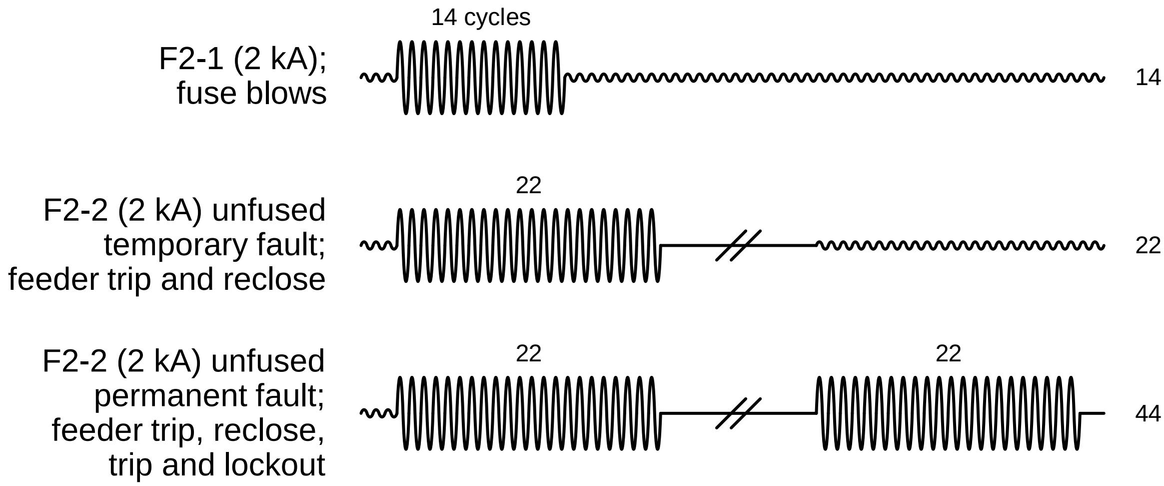
Example main-line and tap faults

Study faults at four locations and two fault levels

- 6 kA F1-1, F1-2
- 2 kA F2-1, F2-2



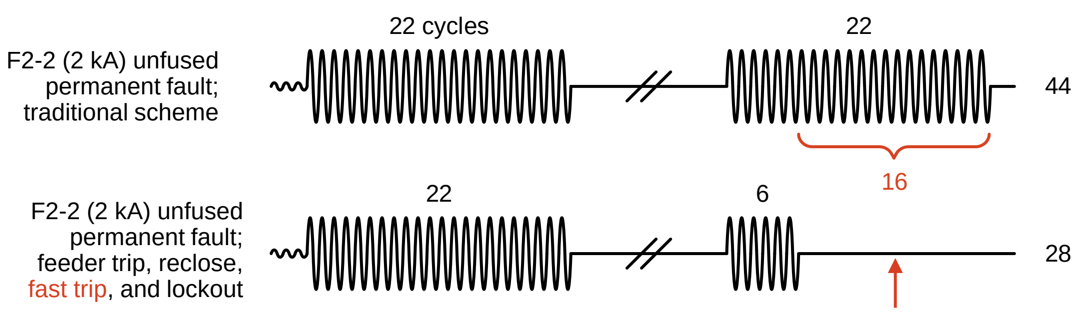
Urban feeder tap and main-line faults (2 kA)



Improvement 1: shorten second fault duration

If relay trips, no fuse is present in fault path

Why use the same time-overcurrent element (coordinated with 100T fuse) when reclosing? Instead, enable short delay element when reclosing

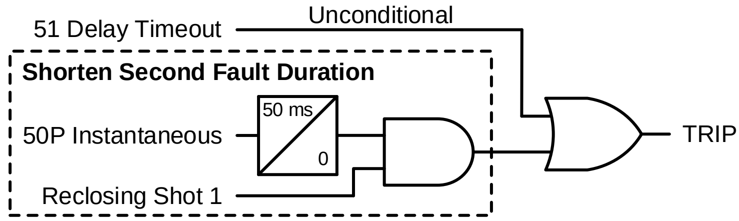


In this example, fault dwell time drops from 44 to 28 cycles (36% fault energy reduction)

Improvement 1: no special equipment needed

Sample logic and energy reduction

- Set 50P overcurrent pickup comfortably above feeder peak load
- Select definite-time delay long enough to filter inrush current

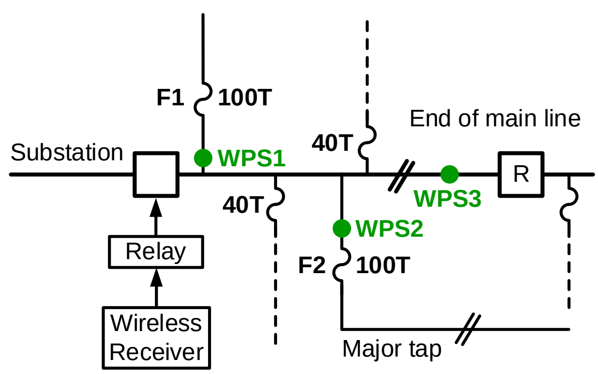


Permanent fault	Dwell time of standard scheme (cycles)	Fault energy (unitless)	Dwell time of Improvement 1 (cycles)	Fault energy (unitless)	Fault energy reduction (%)
1-2 (6 kA)	17	10.20	14.5	8.70	15
2-2 (2 kA)	44	2.93	28.0	1.87	36

Opportunity 2: speed up main-line trip

Identify faulted section *during* fault

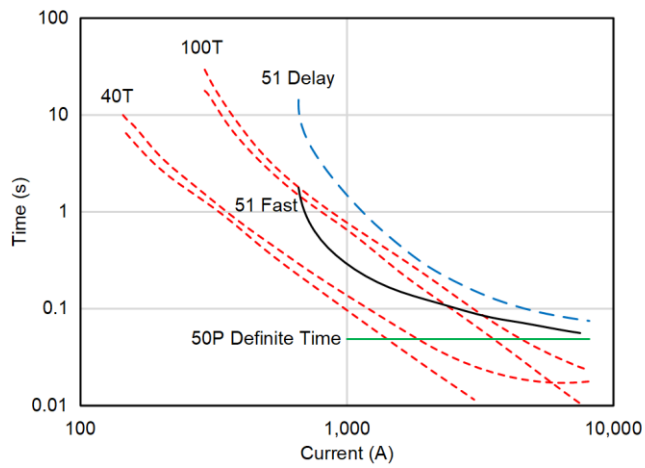
- Introduce fast time-overcurrent element that coordinates with 40T fuses
- Install WPSs on major taps (with 100T fuses) or with Recloser R at end of main line
  - Install antenna and wireless fault receiver at substation
  - Connect receiver to compatible relay or recloser control
- Trip on fast element and perform one reclose EXCEPT when WPS identifies fault on major tap or beyond R



Opportunity 2: speed up main-line trip

Configure fast curve for main-line faults

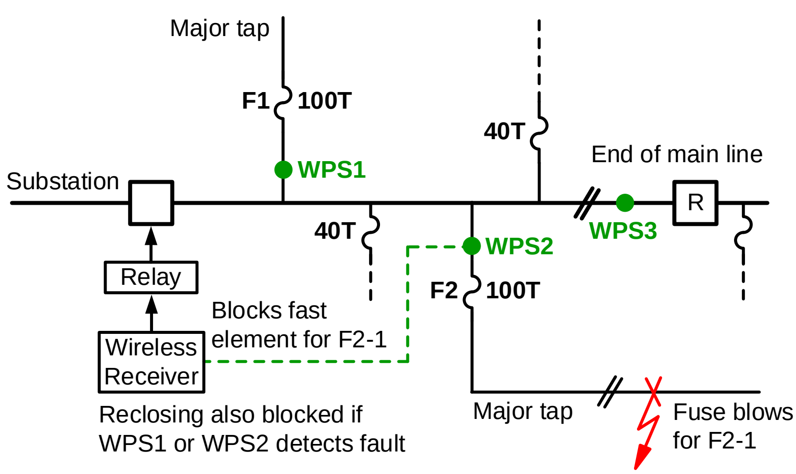
- 51 delay element coordinates with 100T fuses: always active
- 51 fast element coordinates with 40T fuses (and lower)
  - Conditional element only active for main-line and minor tap faults
  - Either fuse blows or feeder breaker trips quickly
  - One reclose attempt allowed
- Technical paper contains relay curve selections used in these examples



Opportunity 2: WPS indicates nonmain-line fault

Fault at F2-1 detected by WPS2

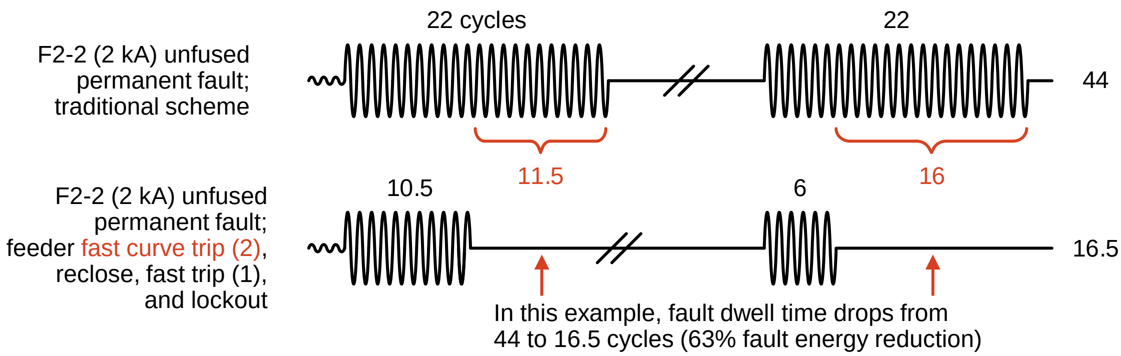
- WPS2 transmits wireless fault initiation signal to receiver
- Receiver communicates signal to relay
- Relay logic blocks 51 fast element
- 51 delay element allows time for F2 to blow
- Feeder does not trip



Improvements 1 and 2: shorten first and second fault duration

If relay trips, no fuse is present in fault path

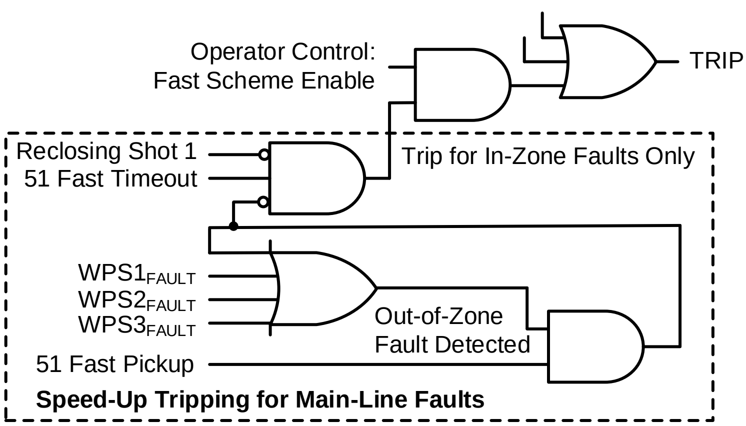
Why use the same time-overcurrent element (coordinated with 100T fuse) when reclosing? Instead, enable short delay element when reclosing



Improvements 1 and 2: sample logic

Addition to Improvement 1 logic

- Any WPS fault signal received during overcurrent condition asserts out-of-zone block
- 51 fast element conditional trip



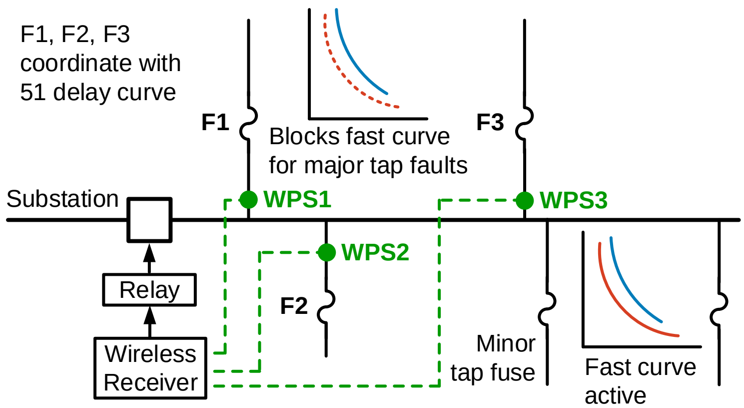
Energy reduction achieved with both Improvements 1 and 2

Fault P = permanent T = temporary	Dwell time of standard scheme (cycles)	Fault energy of standard scheme (unitless)	Dwell time of Improvements 1 & 2 (cycles)	Fault energy of Improvements 1 & 2 (unitless)	Fault energy reduction (%)
1-2 (6 kA) T	8.5	5.10	7.0	4.20	18
1-2 (6 kA) P	17.0	10.20	13.0	7.80	24
2-2 (2 kA) T	22.0	1.47	10.5	0.70	52
2-2 (2 kA) P	44.0	2.93	16.5	1.10	63

Rural distribution feeder

High-risk zone

- Feeder traverses region with seasonal risk (e.g., forested area)
- When fire danger level is extreme, a nonreclose policy is used
- At other times, reclosing is allowed (remotely enabled)
- Faults on major taps blow the fuse
- WPS can speed up main-line fault tripping; required logic implementation is like Improvement 2
- All other fuses (not shown) coordinate with 51 fast curve

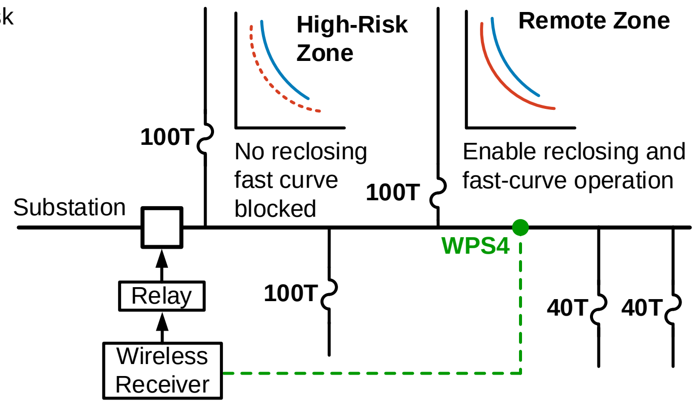


Fast time-overcurrent element blocked if WPS1, WPS2, or WPS3 detects fault; reclosing blocked during high-risk season

Rural distribution feeder

Low-risk remote zone

- Feeder traverses region with seasonal risk
- Remote portion of line is not high risk (e.g., small community)
- During high-risk periods (reclosing disabled) the entire feeder sees an outage, even for temporary faults in remote zone
- By installing WPS4 at zone boundary, feeder reclosing can be enabled only for remote faults, even in high-risk season
- Additionally, fast curve may be enabled for remote zone faults (coordinating with 40T and smaller fuses)



Reclosing enabled only if WPS4 detects fault

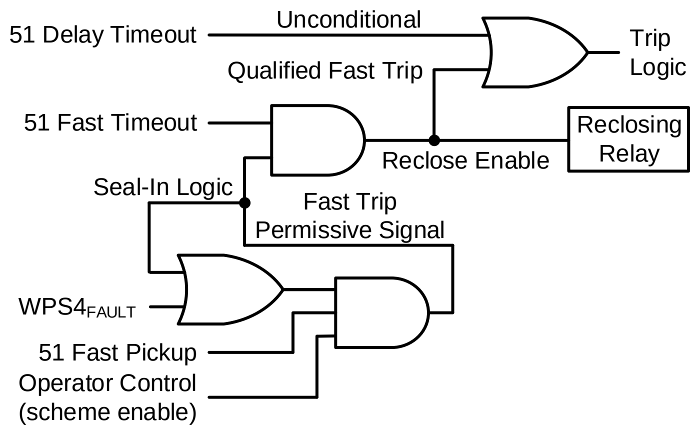
Rural distribution feeder

WPS logic allows reclosing in remote zone

WPS4 fault condition is used in two ways

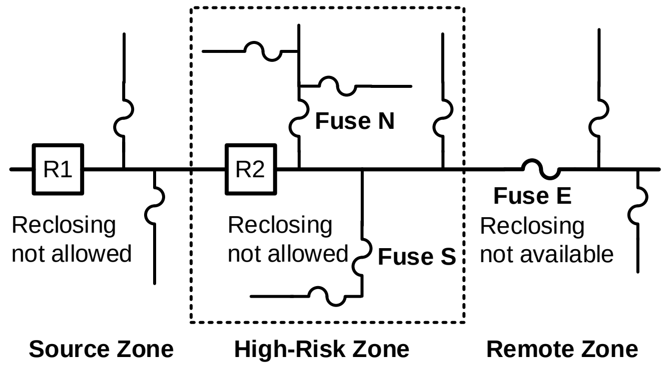
- As a fast-trip permissive signal, tripping for a permanent, unfused fault in remote zone
- As reclose enable signal, allowing feeder breaker to reclose only after tripping for remote zone fault

This remote zone logic improves system availability for all customers on feeder, <u>without</u> affecting fault energy inside high-risk zone



Distribution feeder: central high-risk zone

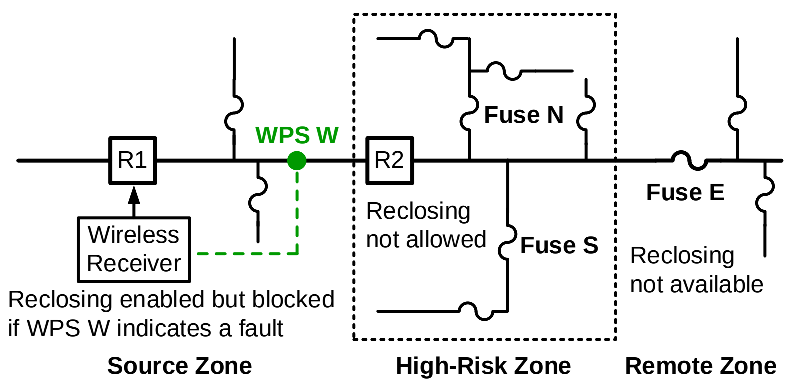
- Only portion of feeder traverses region with seasonal risk
- Nonreclose policy is used seasonally at Recloser R2
- Recloser R1 protects source zone and backs up R2
  - When R2 reclosing is blocked, R1 should also be blocked in case of R2 failure
  - In this situation, any source-zone fault that trips R1 becomes permanent outage
- Allowing R1 reclosing in all seasons improves system availability



Distribution feeder: central high-risk zone

Allow reclosing in source zone

- Install WPS W at end of source zone
- Install antenna and wireless receiver and connect to R1
- Normally enable reclosing at R1
- Block R1 reclosing if any high-risk zone fault triggers WPS W

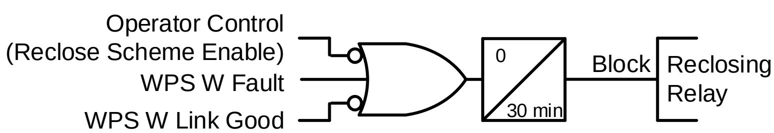


Distribution feeder: central high-risk zone

Allow reclosing in source zone

- R1 reclose blocking logic asserts for any fault in high-risk zone, even if R2 does not trip
- Long dropout timer ensures R1 reclose blocking is available for multiple fuse operations (e.g., in storms)
- Reclosing is also blocked when WPS W link status is down

Recloser R1 Reclose Blocking Logic

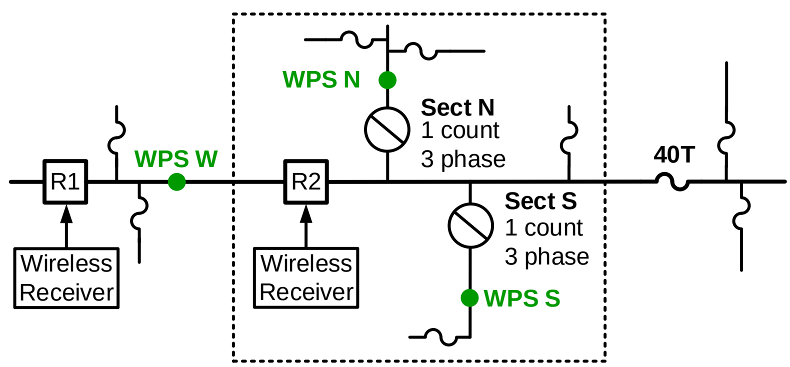


Distribution feeder: central high-risk zone

Isolate all three phases on taps within high-risk area

This example improves safety by eliminating cases where only one tap fuse blows

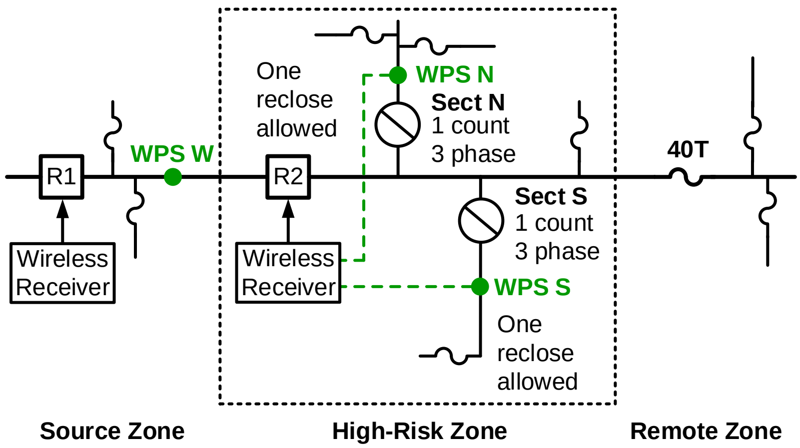
- Install three-phase sectionalizers in place of Fuse N and Fuse S on major taps
- Configure sectionalizer preset count = 1
- Install WPS N and WPS S in tandem with sectionalizers
- Install antenna and wireless receiver and connect to R2



Distribution feeder: central high-risk zone

Isolate all three phases on taps within high-risk area

- Normally block reclosing at R2, except allow one reclose attempt if fault triggers WPS N or WPS S
- Program 51 fast element at R2 to coordinate with largest remaining fuse
- Any fault on N or S tap that causes R2 to trip will also cause sectionalizer to open
- Because sectionalizer opens three phases, subsequent reclose operation should succeed

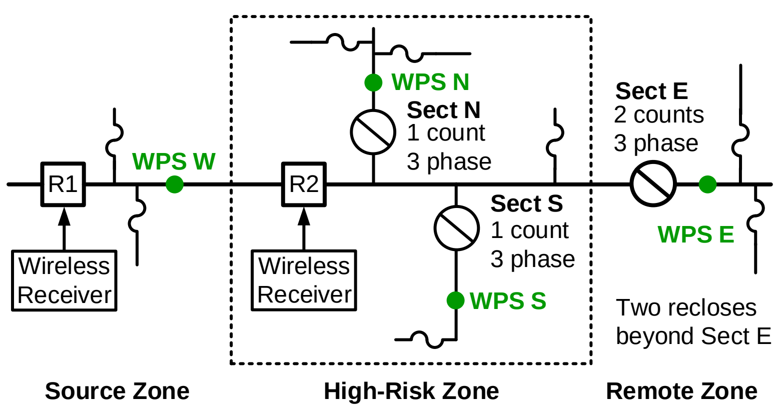


Distribution feeder: central high-risk zone

Allow two reclose attempts for remote zone

This example improves reliability by allowing reclosing for remote zone faults

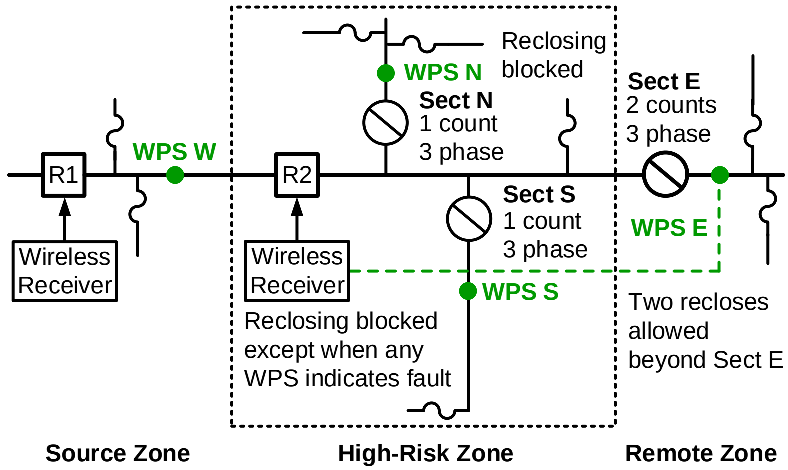
- Install three-phase sectionalizer in place of Fuse E
- Configure sectionalizer preset count = 2
- Install WPS E in tandem with sectionalizer
- Normally block reclosing at R2, except as shown previously, and allow two reclose attempts if fault triggers WPS E



Distribution feeder: central high-risk zone

Allow two reclose attempts for remote zone

- The first fault on the E tap that causes R2 to trip will not open sectionalizer
- R2 recloses the first time and tests line beyond WPS E
- If fault was temporary, R2 remains closed and resets
- If fault returns, R2 trips and Sect E opens three phases
- Because sectionalizer has opened, second reclose operation should succeed



Conclusion

- Fault energy reduction can be achieved through adaptive schemes
- Wireless protection sensors can become part of your toolkit for protection system design

Note: This presentation used idealized examples for clarity; take additional steps and follow best practices when evaluating WPSs for your system

Questions?