Effects of Wide-Area Control on the Protection and Operation of Distribution Networks

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Abstract—**This paper examines the use of wide-area automatic control systems in electric power distribution networks. Today only a small percentage of distribution feeders employ wide-area control strategies. However, this number is growing as distribution engineers and managers respond to concerns about system reliability. Distribution networks are growing in complexity in the face of a coming shortage of electrical expertise as the "baby-boom generation" transitions into retirement. In this changing environment, wide-area automatic control holds the promise of increased system reliability. This paper presents wide-area automatic control strategies and discusses the potential impacts on system operations and system protection practices.**

Topics covered in this paper include:

1. **An overview of wide-area automatic control strategies for distribution networks. This overview presents the objectives and basic operating principles of automatic network reconfiguration in recovering from electrical faults, providing load balancing, and assisting with voltage/VAR optimization.**
2. **The impact on system protection practices. This section discusses how the presence of wide-area control systems affects the protection of the distribution system.**
3. **The impact on system operation practices. This portion discusses how the operation of the distribution system is affected by the presence of wide-area control systems.**

Recommendations will be presented that address potential operations and protection challenges introduced by wide-area automatic control systems.

I. Introduction

Wide-area automatic control systems provide benefits to the distribution network but also introduce some challenges. This paper discusses these benefits and challenges and emphasizes automatic network reconfiguration strategies and their effect on protection and operation practices.

Utility engineers have developed automatic control strategies and applied them in distribution networks for many years. Traditional voltage regulators and reclosers are examples of automatic controls that have well-defined responsibilities. The voltage regulator acts to maintain the voltage in the distribution network within predefined limits. The recloser acts to clear temporary faults and restore power to affected loads. Engineers have also developed voltage-based loop schemes to provide additional attempts to restore load after a permanent fault on simple distribution circuits. These basic automatic controls have played an important role in delivering reliable power to end users.

In recent years, utilities have deployed more sophisticated automatic control strategies that act with a larger scope of responsibility. This has been driven, in part, by the increasing availability of economical communications technologies. Automatic network reconfiguration controllers respond quickly to permanent fault conditions and restore power to de-energized loads. Some of these systems can be applied easily to complex feeder arrangements that are not suitable for simple loop schemes. These control systems also transfer loads automatically to balance load between feeders.

Voltage/VAR optimizing strategies extend the simple regulator control loop to include feedback from measurement points located throughout the distribution network. The objectives of this type of control system vary, depending on the type of load connected to the network. Some utilities are implementing voltage reduction strategies to shave peaks off demand where loads are predominantly resistive. Other utilities are implementing reactive power strategies that automatically control capacitor banks to support voltage along feeders and reduce losses in the distribution network.

As distribution systems become more complex, the opportunities to increase reliability multiply. A utility can take advantage of multiple alternate sources to increase reliability. However, it is not practical to require human dispatchers to perform all the necessary checks and operations. There may be several possible courses of action for a given event. Each course of action may require several operations to be performed in a specific sequence (e.g., switching, tap changes, capacitor banks, protection optimization). Additionally, system checks and safety checks must be performed to ensure equipment ratings are not exceeded and personnel safety is not compromised. Wide-area control systems automate these tasks to allow utilities to take advantage of the opportunity for increased reliability in complex distribution networks. However, the designers and deployers of these sophisticated systems must exercise diligence to avoid potential pitfalls.

Wide-area control systems may degrade the effectiveness of traditional protection practices. After the wide-area control system operates, the distribution network will no longer be in the normal configuration. Protection devices that were coordinated may not be coordinated in the new network arrangement.

Distribution network operation involves interactions with human operators in the control center and in the field. Wide-area automatic controls will take some control decisions away from the dispatcher and introduce new situations that require dispatcher involvement. The design details of the wide-area control system also have effects on power system operations. The effects on the distribution network must be understood to ensure that the safe and effective operation of the network is not compromised.

Section II of this paper provides a brief overview of approaches to wide-area control. Section III describes an example automatic network reconfiguration system used in distribution networks. Section IV discusses subsequent challenges to the protection systems employed on the distribution network. Section V describes challenges to the successful operation of distribution networks that employ wide-area control. Section VI summarizes recommended solutions to address the challenges of wide-area control to protection systems and operations of the power distribution system.

II. Wide-Area Control Overview

A. Control Objectives

Wide-area automatic control is a broad concept that encompasses many system-wide control objectives in the distribution network, including the following:

- Service restoration
- Loss reduction
- Power factor correction
- Voltage optimization
- Load balancing and load shedding
- Enhanced situational awareness

These objectives are interdependent. For example, restoring service to a feeder section may result in overload conditions, excessive voltage drop, or power factor degradation. The control system may need to transfer load from the overloaded feeder to adjacent feeders or perhaps shed noncritical load to alleviate actual or predicted overloads. The control system may also need to adjust voltage regulators to alleviate voltage drops or switch capacitors to correct power factor and reduce losses in the new feeder configuration. In cases where there are multiple alternate feeds that could be used to restore service, the control system will select the alternative that has the least negative impact.

Several supporting functions assist in achieving the main control objectives, including the following:

- Metering and control
- Fault locating
- Fault isolation
- Safety checks
- Operating constraint checks
- Topology analysis
- Reactive power control
- Reliability calculations and logging
- Event recording
- Visualization

The wide-area control system actuates the following typical apparatus found in the distribution network:

- Breakers
- Reclosers
- Motor-operated switches
- Sectionalizers
- Voltage regulators
- Capacitor banks

B. Simple Loop Schemes

Wide-area controls in use today on distribution networks employ strategies that reconfigure the network in response to changing power system conditions. Automatically reconfiguring a distribution network in response to fault conditions can greatly improve the reliability of electrical service, often decreasing outage times from hours to seconds.

Power engineers have designed loop schemes that are very effective for well-defined networks. These schemes operate without communication by monitoring voltage at each switch to detect outages and restore loads. Implementations vary but typically apply to two radial feeders separated by a normally open switch. Voltage-based loop schemes rely on time-coordinated switch operations to isolate faulted line sections and restore service to unfaulted sections. These schemes typically operate to restore load where possible in one to two minutes [1]. This is a dramatic improvement over the time required to restore manually.

This type of scheme benefits from high-speed processing of input and output signals as well as independence from communications systems. The drawback is that control decisions rely on local measurement only. Local field devices have very little awareness of the state of the larger distribution network.

The addition of communications capabilities provides the opportunity to further decrease the restoration time. Utilities have implemented schemes using protection-oriented communications technology to clear faults and restore load in less than one second [2] and, in some cases, only a few cycles [1]. Each relay passes a few pertinent status points to adjacent relays on the circuit at high speeds. The use of communications not only reduces restoration times but also reduces the effects on customers that still have power. A noncommunications loop scheme will test the line and potentially close into a fault, causing a voltage dip for customers that were not affected by the initial fault.

Fig. 1 illustrates a typical voltage-based loop scheme with optional peer-to-peer communication.

C. Complex Distribution Networks

The schemes referred to above are typically applied to two-feeder networks. The possible topologies are few in this network, and thus the necessary logic is limited. Wide-area control systems that manage larger groups of feeders typically require more information to be shared via communications channels. A centralized controller is commonly used to gather data and to provide system-wide control functions for a group of feeders. It is often convenient to locate the controller in a substation associated with one of the feeders being automated. However, the controller could be located anywhere as long as the necessary communications channels are available. The controller monitors network topology, feeder loading, voltage levels, and other valuable information throughout the network. The controller provides system-oriented control decisions to achieve the interdependent control objectives listed earlier.

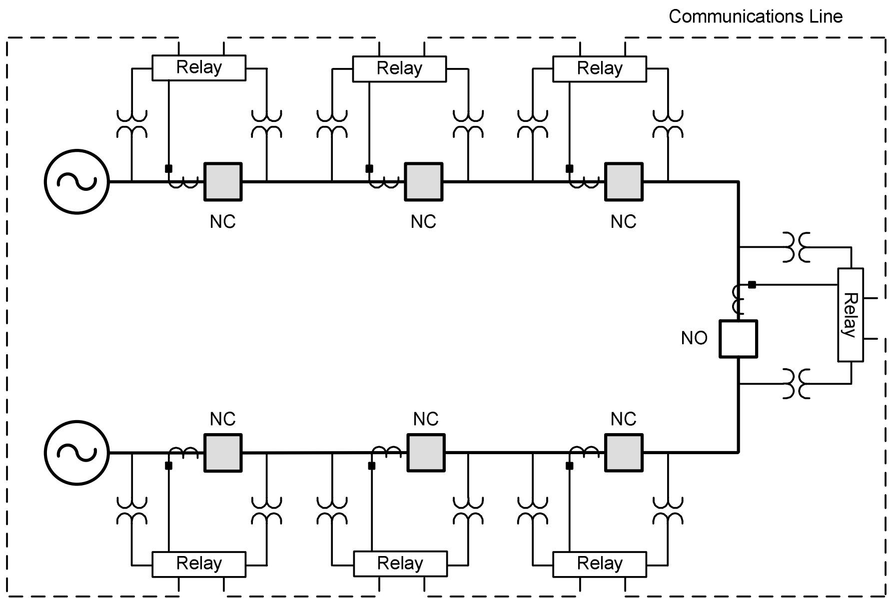

Fig. 1. Simple loop scheme with optional peer-to-peer communication

Fig. 2 illustrates a possible network topology that would benefit from a centralized controller.

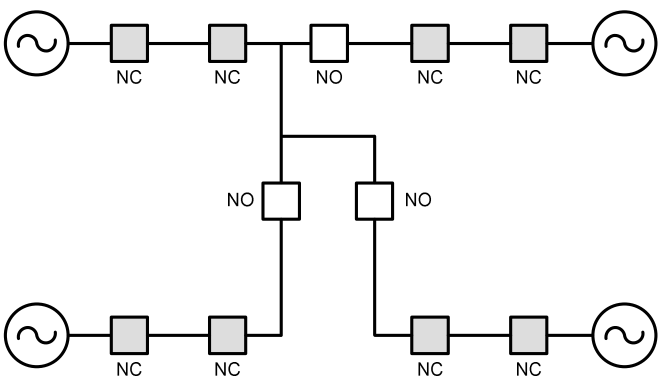

Fig. 2. Multifeeder network

Control functions at the control center benefit from even broader context by monitoring the entire distribution network. Typically, control center implementations benefit from larger computing capacity due to the centralized nature and environmental conditions of the control room. Systems at the control center also usually include sophisticated software applications relating to economic drivers, optimal load flow, and asset management programs.

III. Wide-Area Control Example

This section focuses on one example of wide-area control used in distribution networks. The automatic network reconfiguration (ANR) system detects permanent fault and open-phase conditions on the distribution network. The ANR system acts to isolate the affected section of the feeder and restore power to the unaffected feeder sections from the normal source and from an alternate source if available.

A. Example Distribution Network

Although the ANR system can be applied to a wide variety of feeder arrangements, it is helpful to describe the system operation with respect to an example distribution network. The example network includes three sources, three feeder breakers, and eight reclosers. Two reclosers (R3 and R6) are normally open, and the remaining switching devices are normally closed. The distribution network consists of radial feeders only. The normal configuration of the example network is shown in Fig. 3.

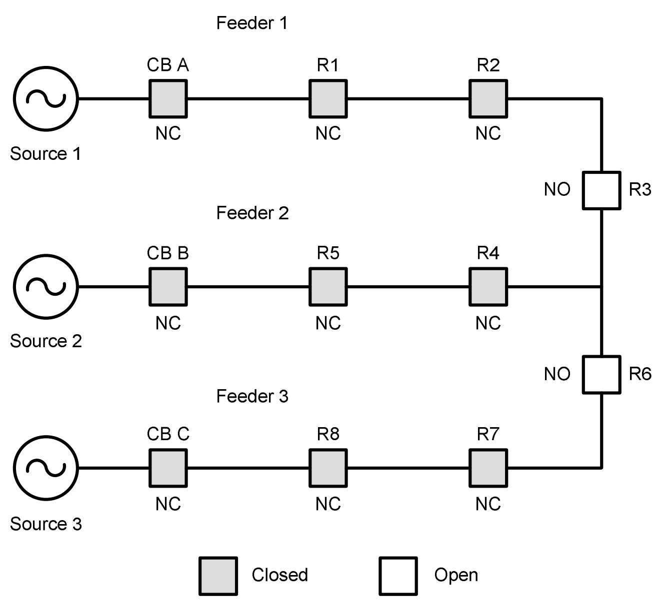

Fig. 3. Example distribution network

The distribution network is comprised of zones. A zone is defined as a section that can be disconnected from the network using switching devices. The example network includes the following zones: CBA-R1, R1-R2, R2-R3, R3-R4-R6, R4-R5, R5-CBB, R6-R7, R7-R8, and R8-CBC. The substation buses are also considered zones but have only one switching device (the feeder breaker) at their boundary. Each zone in the network is energized from only one source at any given time.

The switches in the example network are circuit breakers and reclosers. Motor-operated switches may be incorporated into the control strategy as well. The motor-operated switches are not rated to interrupt current. Care must be taken to ensure that the control system does not attempt to open a motor-operated switch when load current is present. Installing fault indicators with the motor-operated switch provides the wide-area control system with the necessary information to identify the faulted zone. If the fault is downstream of the motor-operated switch, the control system will open the motor-operated switch after an upstream device has cleared the fault. The upstream clearing device is then closed to re-energize the unfaulted section of the network.

Each component in the distribution network has a current-carrying capacity rating. The capacity of each source is a function of the corresponding distribution transformer rating and other loads being fed by the same transformer. The circuit breakers and reclosers have equipment ratings that must be considered as well. The conductors also have current-carrying ratings that must be considered by the control system. It is important to note that the conductor size will vary in many distribution networks. Therefore, the control system must evaluate capacity and loading on a zone-by-zone basis.

The ANR system will respond to permanent faults or open-phase conditions on any of the network zones. For example, the protection device at R1 clears a permanent fault on Zone R1-R2. This leaves Zone R2-R3 de-energized even though there is no fault on this zone. The ANR system acts to isolate the faulted zone from the remainder of the feeder by opening R2. The ANR system then restores power to the loads on Zone R2-R3 by closing R3.

If a permanent fault occurs on Zone R4-R5, the ANR system isolates the faulted zone by opening R4. In this case, Zone R3-R4-R6 is left de-energized. The ANR system must choose between two alternate feeds to restore the load. It will either close R3 or R6. To make this decision, the ANR system evaluates the following:

- Load connected to the de-energized zone
- Available capacity of each alternate feed
- Live-voltage indication of each alternate feed
- Communications health to all related devices
- Abnormal conditions related to each feed

B. Control System Architecture

A dedicated controller is at the center of the ANR system. This controller includes the entire set of feeders in its control scope. Utilities have installed intelligent electronic devices (IEDs) for many years. IEDs such as modern protective relays and recloser controls provide local measurement and control capabilities. The ANR controller communicates with these IEDs and does not require additional interface hardware at each switching device.

Fig. 4 shows the simplified control system architecture for the example distribution network. The ANR controller is located in the same substation as the protective relay for Circuit Breaker CB A. The controller communicates with the CB A relay via a direct serial connection. Since the other two circuit breakers are located in other substations, the ANR controller communicates with them by radio connections. Similarly, the ANR controller communicates with all of the relevant recloser controls via radio as well. The simplified diagram shows one radio at the ANR controller and one radio at each of the relevant IEDs. The actual radio installation depends on several factors such as distances, terrain, and congestion.

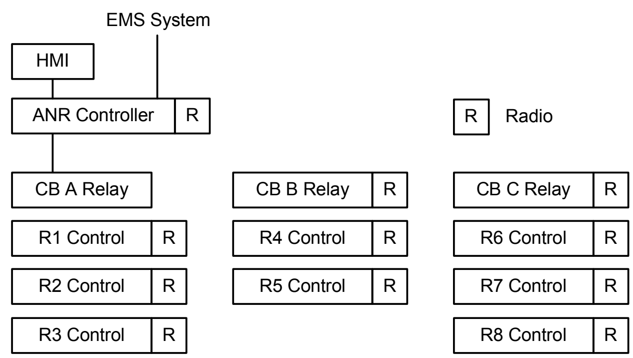

Fig. 4. Wide-area control system architecture

The protective relays and recloser controls provide the physical interface to the circuit breakers and the reclosers. These IEDs provide the following input and output signals to the wide-area control system:

- Switch open/close indication
- Live/dead voltage indication
- Fault current indication
- Recloser lockout indication
- Load current
- Abnormal condition indication
- Open/close commands
- Settings group change commands

The ANR controller collects data and sends control commands to the protective relays and recloser controls using the DNP3 protocol. Data are transmitted from the end devices using unsolicited messages as conditions change. The ANR controller also polls each end device periodically to ensure that the end device is still healthy. The ANR controller sends DNP3 control messages as required by the automatic sequence.

The ANR controller includes a local human-machine interface (HMI). The HMI is not necessary for the controller to operate. However, local visualization is very helpful during initial installation and commissioning of the control system. It is also convenient for post-event analysis activities once the control system is in service. The HMI includes the following features:

- Status and control
- One-line diagram
- Alarm annunciation
- Automation sequence status
- Sequence-of-events viewer

The ANR controller is a node on the utility's energy management system (EMS). The controller provides data to the EMS from all end devices within its scope of control. The controller also provides information about the ANR sequence itself. Dispatchers can control individual end devices and control the ANR system via the EMS connection to the controller.

C. Sequence of Operation

The ANR controller executes a straightforward sequence. Fig. 5 illustrates the sequence of operation of the ANR system.

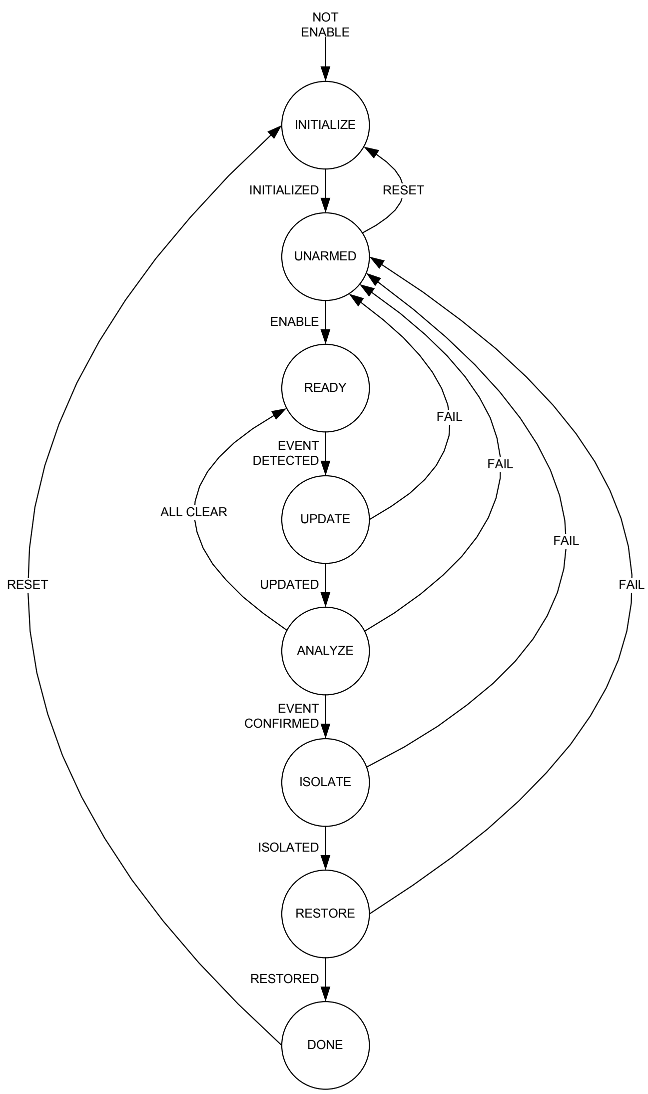

Fig. 5. Sequence of operation

The Initialize step is executed when the controller first turns on, when an operator disables the sequence, or when an operator issues a **RESET** command while the sequence is unarmed or done. The Initialize step acts to reset internal variables and alarm conditions. During this step, the distribution network configuration is evaluated to determine the normal operating arrangement. Once the Initialize step has executed, the sequence transitions to the Unarmed step.

The Unarmed step is executed after the Initialize step is completed successfully or if a sequence failure occurs during the Analyze, Isolate, or Restore steps. The Unarmed step monitors for the **ENABLE** command to be issued by an operator. If this command is detected, the sequence transitions to the Ready step. The Unarmed step also monitors for an operator-issued **RESET** command, which, if detected, returns the sequence to the Initialize step.

The Ready step is executed when an operator enables the system. The system will also return to the Ready step if an event is detected but clears after the Analyze step without need for intervention. In the Ready state, the system monitors for an event that requires further analysis. An event may be an undervoltage indication or a fault indication reported by a recloser control or feeder relay. The event detection is supervised to ensure that events are ignored if they correlate with abnormal conditions on the related circuit, such as abnormal circuit configuration, hot-line tags, nonreclose status, supervisory control disabled, or communications failure. Once an event has been detected, the sequence transitions to the Update step.

The purpose of the Update step is to allow an integrity poll of all devices to be completed. This is done in order to base all subsequent decisions on up-to-date information about the distribution network. Additionally, this integrity poll verifies that each device is responsive. If a device does not respond, a communications alarm is generated. Once the integrity poll is complete, the sequence transitions to the Analyze step.

The purpose of the Analyze step is to determine if a permanent fault has occurred or an open-phase condition exists. The analysis is supervised to ensure that it is blocked if abnormal conditions are present on the related circuit. Abnormal conditions include hot-line tags, nonreclose status, supervisory control disabled, or communications failure. If the system determines that a permanent fault or an open-phase condition exists, the sequence transitions to the Isolate step. If the system determines that the event condition no longer exists, the sequence returns to the Ready step.

The Isolate step is executed when the system has identified a feeder section that has a permanent fault or an open-phase condition. The purpose of the Isolate step is to open switching devices connected to the affected zone. The controller evaluates each switching device on the boundary of an affected zone to determine if it should be opened. If there are de-energized zones downstream of the affected zone and an alternate feed is available to restore the de-energized zones, the switching device is opened to isolate the affected zone from the unaffected de-energized zones.

The Restore step is executed when the system has successfully isolated the feeder section that is faulted or has an open-phase condition. If there are de-energized zones downstream of the affected zone that have been isolated from the affected zone, the system attempts to restore these zones from an alternate feed by closing a normally open tie-point connection to an adjacent feeder.

Once the Restore step has executed, the sequence transitions to the Done step. In this state, the dispatcher can reset the sequences to transition back to the Ready step.

D. *Abnormal Conditions*

There are situations when automatic reconfiguration is not desirable. The ANR controller considers the following to be abnormal conditions:

- Hot-line tags
- Local control mode
- Nonreclosing mode
- Device diagnostic failure
- Communications failure
- Command failure

If an abnormal condition is present on any switching device associated with a feeder, the entire feeder is considered to have an abnormal condition. For example, if R2 has a hot-line tag present, the entire radial feeder associated with Source 1 is considered to have an abnormal condition. A feeder that has an abnormal condition is excluded from the ANR control strategy. The ANR controller will not respond to events on this feeder, and this feeder will not be considered as a valid alternate feed.

IV. System Protection Considerations

A. *Time-Overcurrent Coordination*

Overcurrent detection is the predominant protection method used for distribution feeders. The principle is well understood and straightforward to implement. Engineers select standard time-current curves, pickup values, and time dial settings to coordinate the operation of multiple protection devices on a radial feeder. The objective is to operate as fast as possible for faults in the primary zone, while delaying operation for faults in the backup zone. Fig. 6 illustrates time coordination of three overcurrent devices on a radial distribution feeder.

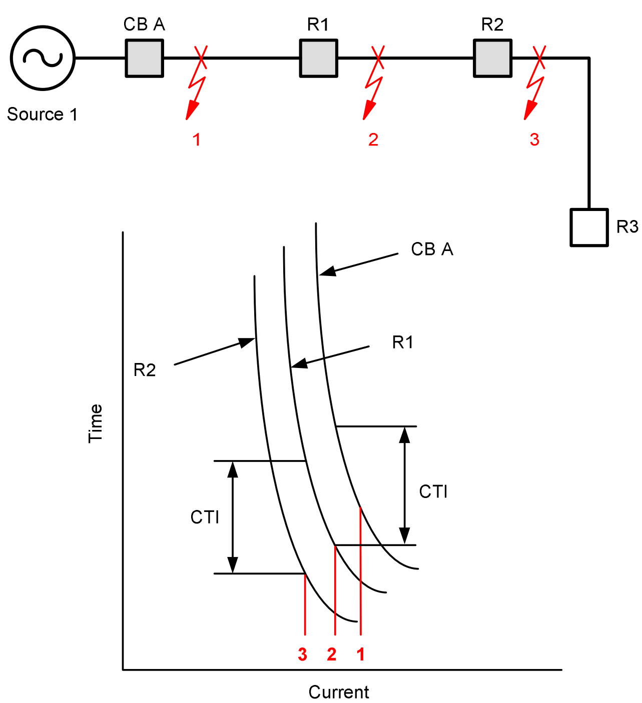

Fig. 6. Simplified time coordination for a distribution feeder

The engineer derives the protection settings from a knowledge of the available short-circuit current and the desired coordination time interval (CTI) between devices—typically 0.3 seconds or greater. Automatic network reconfiguration results in network configurations that render the protection settings ineffective. Coordination of overcurrent devices is not necessarily maintained. Power flow direction is reversed in some areas when the loads are fed from a different source. Additionally, the available fault current levels may be significantly different in the new configuration. Fig. 7 illustrates the altered coordination requirements after the feeder has been reconfigured. Reclosers R1 and R2 no longer need to coordinate with the Feeder Breaker CB A. R2 must now coordinate with the normally open Recloser R3. The fault currents at Faults 2 and 3 will likely have changed as well.

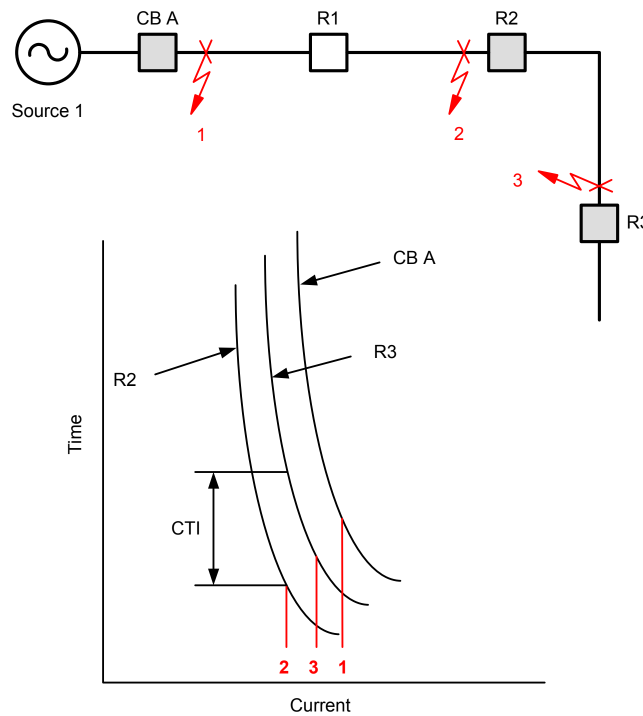

Fig. 7. Alternate configuration with alternate coordination

For this reason, some ANR systems will revert to a switch mode of operation after the initial fault is detected and the distribution network has been reconfigured. These systems purposely defeat protection in devices outside the substation when the circuit is not in the normal configuration. Protection is provided solely by the feeder breaker relay in the substation. This approach removes the problem of poor coordination by removing the coordination altogether. Subsequent faults on the feeder will cause the feeder breaker to operate even if a recloser located closer to the fault could have removed the fault. In this case, the end result is that load is de-energized unnecessarily.

Fig. 8 illustrates the operation of the protection system for systems that revert to a switch mode of operation. All five reclosers are in switch mode due to a previous fault and reconfiguration. If a subsequent fault occurs between R1 and R2 while the reclosers are in switch mode, the feeder relay at

Breaker CB B will operate to clear the fault. The load on the feeder between CB B and R2 is de-energized unnecessarily if the reclosers are operated in switch mode. Note that on many distribution circuits, it may not even be possible to set the relay at CB B sensitive enough to see a fault past R2 and still be set high enough to carry load. In this case, CB B would not trip, and the last section of the feeder would be unprotected.

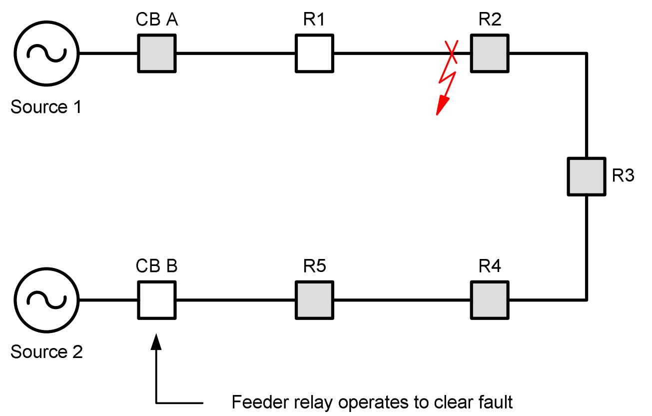

Fig. 8. Subsequent fault while in switch mode

Protection systems can be set up to adapt to changing conditions caused by the operation of the wide-area control system. Modern microprocessor-based protective relays support programmable logic and multiple settings groups. Wide-area control systems that take advantage of these features guard against compromising the protection system. These control systems implement a step in the automatic sequence to validate the state of the protection system. If necessary, the control system issues commands to protective relays and recloser controls to change settings. In this way, the wide-area control system adapts the protection system to fit the new network configuration before the system is reconfigured. Coordination studies must be performed with all valid operating configurations.

B. Voltage and Loading

When switching load from one circuit to another, a dispatcher will verify that the circuit is capable of supplying the additional load. The dispatcher considers the voltage level of the receiving circuit as well as the available capacity compared to the amount of load being transferred. An ANR system will act automatically and not give the dispatcher the opportunity to validate these conditions. The wide-area control system must perform these basic checks to avoid overload and excessive voltage drop conditions.

Ideally, voltage should be measured on both sides of all normally open tie points in the network. This will allow the dispatcher or the control system to check for healthy voltage levels on adjacent feeders as part of the process of choosing an alternate source to pick up load. If voltage is not measured directly at the tie point, measurements may be considered from devices on the same section.

In Fig. 9, the protection device at CB A has cleared a fault between CB A and R1. The loads between R1 and R3 are de-energized. These loads could be re-energized from Feeder 2 by opening R1 and closing R3. The dispatcher will check to ensure that healthy voltage is present on the alternate feeder. The preferred location to check for voltage is on the Source 2 side of R3. However, if this voltage is not measured, there are alternate locations that could be examined to determine if there is healthy voltage on the zone. Voltage measurements at R6 or R4 can provide live-voltage indications. The wide-area control system is aware of all of these possible locations and will automatically select the best location for the situation.

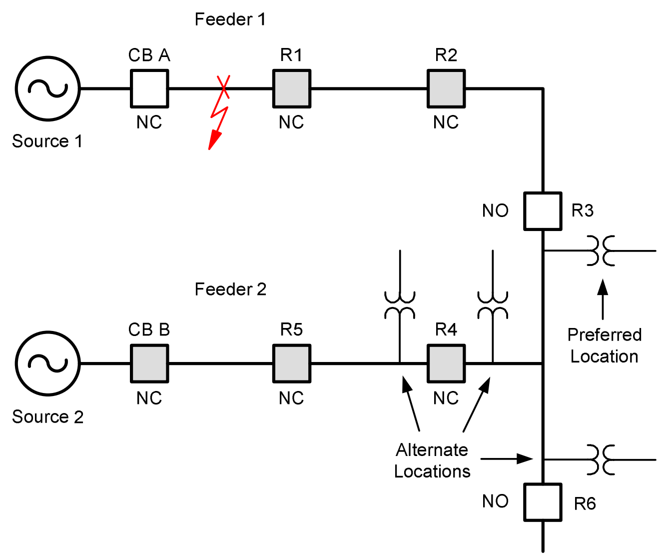

Fig. 9. Locations of voltage indication

Inadvertent overloads cause thermal damage to cable systems. Wide-area control systems must consider loading before automatically reconfiguring the network. The control system should consider the following three aspects of loading:

- Amount of capacity available on alternate feeds
- Amount of load to be re-energized
- Load changes over time

It is important to note that conductor sizes may vary throughout the distribution system. Therefore, the control system must evaluate the capacity and load on each section of the feeder to determine the overall capacity of the alternate feed.

Relays and recloser controls measure current. The wide-area control system collects these measurements and does simple arithmetic to calculate the amount of load that is connected to each section in the network. The load is simply the current entering the section minus the current exiting the section. When a fault occurs that leaves parts of the network de-energized, the control system uses a memory of the load prior to the fault while it attempts to find an alternate feed.

Overloads develop over time due to daily load profile. For example, automatic reconfiguration at 5:00 a.m. results in no overload conditions. However, by the middle of the afternoon, the circuit may be reaching its limit. Wide-area control systems can apply load-balancing techniques to transfer load between adjacent feeders to alleviate overloads that develop over time. In situations where load transfer is not possible, the control system can shed less critical loads to preserve more critical loads.

C. Miscoordination

Occasionally, protective relays miscoordinate, resulting in tripping more load than was necessary. In Fig. 10, a fault has occurred between R1 and R2. The relay at CB A and the recloser control at R1 both see fault current. Breaker CB A trips and goes to lockout. Recloser R1 should have cleared the fault, but it did not, due to miscoordination.

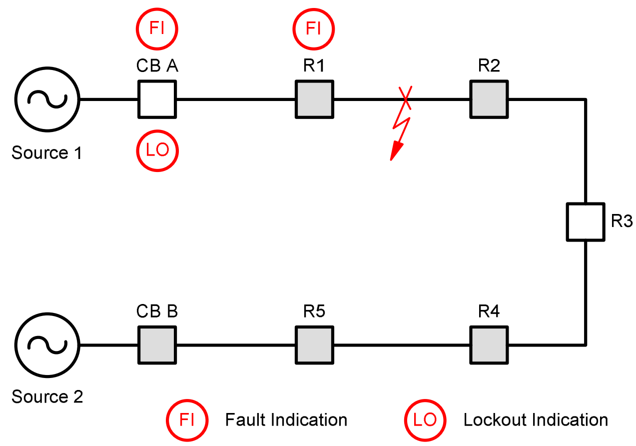

Fig. 10. Miscoordination of protection devices

There are several causes of miscoordination, including settings errors, misapplications, erroneous short-circuit studies, and unforeseen circumstances. Occasionally, distribution engineers have to deal with long circuits with several reclosers on the main line. In order to achieve a reasonable clearing time at the station breaker, very small coordination margins may be used. In these cases, some amount of miscoordination is expected.

Wide-area control systems have a larger scope of measurement than do the individual relays in the network. A wide-area controller will detect miscoordination events, based on the circuit topology, fault indications, and lockout indications. In Fig. 10, the wide-area controller will open R1 and R2 to isolate the actual faulted section. It will then close R3 to energize Section R2-R3. The control system will also close Breaker CB A to re-energize Section CBA-R1. Additionally, the wide-area controller will alarm the miscoordination event and provide data that engineers can use to correct the problem.

V. System Operation Considerations

Wide-area control systems affect the operation of power distribution systems in several ways. The effects can be described in terms of day-to-day operations and control system design choices.

A. System Checks and Safety Checks

One way to evaluate the effects of wide-area control on operations is to consider what a dispatcher would consider. When transferring load from one feeder to an alternate feeder, a dispatcher will consider the impact that the operation will have, asking basic but essential questions:

1. Will the operation result in exceeding predefined system limits?
2. Will the operation result in potentially unsafe conditions?

Failure to consider these questions may result in equipment damage or injury to personnel. If a wide-area control system automatically transfers load from one feeder to an alternate feeder, the dispatcher is no longer in the decision-making path. If the control system does not have appropriate checks, undesirable operations are inevitable.

For this reason, the control system must implement system checks to determine if the alternate feeder is capable of feeding the loads to be transferred. This was discussed in the previous section. The control system must also implement checks to ensure that the operation does not conflict with any crew activities. One way to address this is to have the control system monitor for any indications of crew activity, such as the following:

- Hot-line tags
- Nonreclose status
- Local control mode

The wide-area control system can easily monitor indications from all switching devices on the feeder. If any of these indications are present on any switching device, the operation is blocked. In this way, the control system can avoid automatic operations related to feeders where utility crews are working.

Additional checks can guard against other undesirable operations. For example, a communications failure to one recloser on a feeder should block all automatic operations related to that feeder. When a communications failure occurs, the control system no longer has visibility and cannot tell if indications of crew activity are present at the offline device.

B. Feeder Breaker Control Inhibit

In many cases, wide-area automatic control systems are implemented on parts of the distribution network that previously were not remotely controlled by the dispatcher. Dispatchers may not have concerns about automatic operation of devices outside the substation. However, since the feeder breaker has been under their exclusive control in the past, dispatchers may have concerns about allowing an automatic system to control it.

Many strategies can still be implemented by controlling only reclosers and motor-operated switches outside the substation. However, automatic control of the feeder breaker will allow better performance of the control strategy in some situations. For example, if a loss of voltage occurs on the substation bus, the control system can automatically open the feeder breaker. The entire feeder can then be re-energized from an alternate source. However, if control of the feeder breaker is not allowed, the first recloser outside the substation would be automatically opened instead of the feeder breaker. The feeder beyond the first recloser would then be re-energized from an alternate source. In this case, the feeder section between the substation and the first recloser is left de-energized unnecessarily.

Automatically controlling the feeder breaker may not be a concern at some utilities. But if it is a concern, the wide-area control system should support a control-inhibit function that adapts the control strategy to fit the operational comfort level. As time passes and the control system proves itself to be reliable, dispatchers will gain confidence in the system. Removing the "inhibit" from the feeder breaker is a simple task.

C. Return to Normal

Wide-area control systems will automatically reconfigure the distribution network to restore load or relieve potential overload conditions. The reconfiguration may include several switch operations and changes to protection settings in multiple devices. These operations are executed in a specific sequence. Additionally, the system performs validation checks to ensure system limits are not exceeded and safety is not compromised.

At some later time, a dispatcher will have to return the distribution network to its normal arrangement. The dispatcher must perform a sequence of operations similar in complexity to the sequence performed by the control system in the initial reconfiguration. In the case of complex networks with several tie points, this can be a time-consuming task. Since the control system may have changed protection settings in several devices to preserve coordination, the dispatcher must know what the normal protection settings should be. The dispatcher will typically not be aware of this level of detail.

In order to address this issue, the wide-area control system should include a return-to-normal function. This function allows the dispatcher to initiate the sequence to return the network to its normal arrangement with a single command to the control system. The control system will then execute the appropriate sequence of operations to return the switches and protection settings to the normal arrangement.

D. Equipment Interface Flexibility

Some wide-area control systems utilize specialized devices to interface with the primary apparatus in the network. This approach results in duplication of control devices in the network, ultimately driving up the cost of installing and operating wide-area controls.

Well-designed wide-area control systems leverage existing assets. Modern protective relays and recloser controls have the necessary monitoring and control capabilities as well as communications capabilities. The wide-area controller should allow interface to these existing devices. Typical wide-area control strategies such as ANR require only a small set of data and control points for each device in the system. The data requirements are well within the capabilities of modern IEDs already in use in many distribution networks.

Interfacing to existing devices will reduce training costs compared to those associated with introducing new equipment. Using existing IEDs as the field devices reduces the amount of training required to familiarize line crews with the wide-area control strategy. For example, if existing recloser controls are used as the end devices in the wide-area control system, field crews can be trained on a few new indications on a device they are already familiar with.

E. Straightforward Implementation

Some wide-area control systems require significant amounts of detailed engineering to adapt the control system for specific installations. This tendency can quickly consume engineering resources, severely reducing the number of feeder groups that a utility is able to automate. There are many potential differences between installations, including the following:

- Number of sources
- Number of tie points
- Number of switching devices
- Diversity of device types (breakers, reclosers, motor-operated switches)
- Location and number of voltage measurements (e.g., source and/or load side of switching device)
- Capacities of feeder sections

In order for a utility to gain widespread advantages, wide-area automatic control strategies must be straightforward to implement on diverse circuit arrangements.

F. Operator Interfaces

A side effect of automating the distribution network is that more data become available to the control center. Information that was previously islanded in standalone recloser controls becomes accessible via the SCADA interface on the ANR controller. This is a great benefit because it adds to the dispatcher's situational awareness. However, it can also have a negative effect if the data are not organized. Some systems forward large amounts of unorganized data to the control center. In the end, this approach is not sustainable because operators become frustrated. They are forced to sift through large amounts of data to find the one piece of information that is important at the time. The negative impact of large amounts of unorganized data becomes more pronounced as more feeders become automated.

A more sustainable approach is to forward a small subset of the available data to the EMS system to give the dispatcher better situational awareness and critical indications and alarms from the control system. A local HMI at the wide-area controller can be used to log detailed sequence-of-events data for post-event analysis without burdening the connection to

SCADA. The addition of satellite-synchronized clocks at each switching location ensures that all sequence-of-events data are precisely time-tagged to aid with post-event analysis. The local HMI can play a critical role in determining how the control system is performing.

VI. Recommendations

The following recommendations follow from the discussion presented in this paper:

1. Control protection settings groups in relays and recloser controls to preserve effective coordination after network reconfiguration.
2. Supervise wide-area controls with voltage measurements to avoid inducing excessive voltage drops.
3. Supervise wide-area controls with capacity and load measurements for individual feeder sections to avoid overloading.
4. Use a wide-area controller to detect miscoordination of protection devices and restore loads de-energized due to miscoordination.
5. Supervise wide-area controls with hot-line tag, local control mode, and nonreclose indications to avoid operating switching devices where crews may be at work.
6. Automatically exclude from the control scheme feeders that present any abnormal conditions.
7. Specify an automated return-to-normal function to assist the dispatcher after repairs have been made.
8. Specify a control-inhibit function to allow dispatchers exclusive control over the feeder breaker.
9. Incorporate existing relays and recloser controls into the wide-area control system where possible to reduce costs associated with installing, commissioning, and operating the wide-area control system.
10. Forward data from the wide-area controller to the utility EMS to provide expanded visibility. However, exercise diligence to avoid overloading the operators with extraneous data.
11. Implement a local HMI with the wide-area controller to aid with commissioning, training, and post-event analysis.

The future promises more advanced control algorithms to accommodate distributed generation as well as provide security assessment, demand management, and other valuable functions in distribution networks. There is little doubt that sophisticated automatic control systems are, and will continue to be, important factors in the mission to deliver high-quality, reliable power. The designers and deployers of these sophisticated systems must exercise diligence to avoid potential pitfalls.

VII. References

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VIII. Biography

Will Allen received a BSEE from the University of Alberta in 1993. He has experience in the fields of industrial control systems and power system automation. He joined Schweitzer Engineering Laboratories, Inc. in 2000 as an automation engineer and currently serves as an integration application engineer. He is a member of the IEEE and a professional engineer in the provinces of Alberta and Ontario and the State of Washington.

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