Electrical Switchgear Protection and Control Scheme Design Techniques to Improve Security and Dependability

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ELECTRICAL SWITCHGEAR PROTECTION AND CONTROL SCHEME DESIGN TECHNIQUES TO IMPROVE SECURITY AND DEPENDABILITY

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Abstract — Protection and control circuit design plays a critical role in the correct, desired operation of circuit breakers. Redundancies in protection and control circuit design are implemented to improve system reliability (security and dependability). This paper presents protection and control circuit designs of increasing redundancy and complexity and their impact on the reliability of power system operations. The paper focuses on voting schemes using multiple relays. In addition, the paper discusses some considerations and recommendations for designing a more reliable scheme, including various hardware redundancies, such as battery or direct current source redundancy, breaker trip coil circuit redundancy, and redundancy in the inputs to the relay. Many of the schemes presented in this paper have been implemented in switchgear, tested, and are in service. The schemes presented in this paper are explained with figures of the protection and control circuits that illustrate their applications.

Index Terms — Protection and Control, Control Circuit Design, Security, Dependability, Reliability.

I. INTRODUCTION

Protection and control (P&C) schemes are employed in the electric power system to mitigate disturbances, such as faults, and prevent cascading impacts within the electric power system. Hence, it is important that a misoperation of a control action (such as opening or closing a circuit breaker) does not occur. For this purpose, redundancies in the P&C design are implemented to improve system reliability (security and dependability). The IEEE Power System Relaying and Control Committee developed IEEE C37.120, *IEEE Guide for Protection System Redundancy for Power System Reliability* [1], to serve as a reference for implementing redundancy in power system design. The IEEE guide presents general considerations for redundancy, component effects on protection system redundancy, and considerations based on the application. This paper focuses specifically on the control circuits of the protection system.

According to the IEEE guide, a well-designed protection system should balance technical requirements, reliability concerns, and costs with the goal of achieving a robust design that is simple to operate and maintain [1]. In power system protection, dependability is a measure of the certainty that the intended protection system will take the necessary and correct action, such as tripping a circuit breaker during a fault or abnormal condition. On the other hand, security is a measure of the certainty that the protection system will not take any action in the absence of a fault or abnormal condition. Reliability is the combination of both dependability and security. References [2] and [3] provide mathematical formulations for quantifying these reliability metrics.

References [1], [3], and [4] explain the difference between redundant and backup schemes. In protective relaying, redundant systems are additional systems with adequate performance to independently meet the system requirements. Furthermore, redundant systems need not be identical. A backup system provides a protection scheme for the same zone of protection as the primary protection but may be of a lower degree of performance or configured to operate upon the failure or loss of service of the primary protection system.

For P&C circuit design, the devices are all typically primary devices in a scheme with redundancy. The redundant devices perform the same application and have the capability to perform control actions. For example, for a protection application, the same protection zone is protected by multiple relays and all the relays can monitor and make control decisions independently. Each relay in this case has the authority and capability to operate the circuit breaker independently.

This paper shares P&C circuit designs of increasing redundancy and complexity to guide the readers regarding the impact on reliability for each scheme. The schemes are presented with figures of the P&C control circuit to illustrate their applications. From the authors' experience, many of the schemes presented in this paper have been implemented in switchgear, tested, and are in service. The paper also discusses other redundancy considerations that can supplement the system's reliability, such as hardware redundancies, including battery or direct current (dc) source redundancy, breaker trip coil circuit redundancy, and redundancy in inputs to the relay. Though this is not a comprehensive list of redundancies that can be implemented in the P&C circuit design, the paper covers some of the essential redundancies that can be implemented to significantly enhance the reliability of the system. Sections II.A and II.B introduce one-relay and two-relay schemes. Section II.C presents voting schemes using three relays and application considerations for multirelay schemes. Section II.D discusses hardware redundancies. Section III presents the conclusion.

II. P&C CIRCUIT DESIGNS

In P&C circuit design, the dependability of a scheme can be increased by trying to perform the same circuit breaker control operation using multiple pathways (for example, parallel connection of multiple relay contacts or the circuit equivalent of the OR logic function). The security of a scheme can be improved by ensuring multiple decision-making devices end up with the same control action (for example, a series connection of relay contacts from different relays or the circuit equivalent of the AND logic function).

In this paper, a relay is considered healthy when the relay has control power and has not disabled itself due to internal self-diagnostics. A relay is considered unhealthy when it is taken out of service or is not in a normal, functional state. The paper considers microprocessor digital relays with programmable logic for operating the output contacts in the control circuit for circuit breaker operation. The legend for the P&C circuits in this paper is presented in Figure 1. The schemes in this paper are presented using a breaker trip coil but they are applicable to a breaker close circuit or any other P&C circuit application.

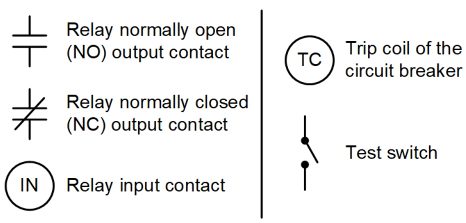

Figure 1 Legend for the P&C Circuits Presented in This Paper

A. *Single-Relay Scheme*

The single-relay scheme is the simplest form of P&C circuit design with no or minimal redundancy. A single output contact from a relay is used to operate the circuit breaker, as shown in Figure 2(a). This scheme has the lowest security and dependability in terms of P&C circuit design compared to the multirelay schemes discussed in this paper.

Marginal redundancy can be introduced by having multiple relay contacts from the same relay connected in parallel to perform the circuit breaker control action, as shown in Figure 2(b). Though this practice is uncommon, it can protect against a relay contact failure.

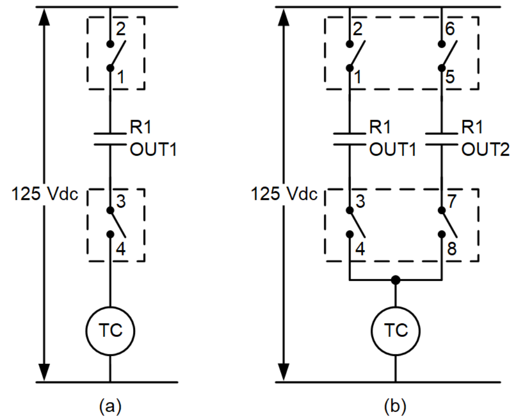

Figure 2 (a) Single-Relay Scheme—Single Output Contact (b) Single-Relay Scheme—Multiple Output Contacts From the Same Relay

B. *Two-Relay Scheme*

When the relay is unhealthy in the single-relay scheme, it leaves the system inoperable, thus severely lacking in dependability. Furthermore, improper inputs to the relay, such as loose wiring connections, or incorrect settings in the relay can cause the relay to misoperate, thus lacking in security as well. The reliability can be improved by adding another relay to the P&C circuit.

1) *Two-Relay Scheme—Relay Output Contacts Connected in Parallel:* In this two-relay scheme, R1 and R2 are two redundant relays and each relay has an output that is connected in parallel, as shown in Figure 3, to operate the circuit breaker. The circuit breaker operates when at least one of the relays asserts its output contact (OUT1). When there is a relay failure, the other relay can operate the circuit breaker, thus improving the dependability of the scheme. However, the security of the scheme can deteriorate, as either relay can misoperate and cause an unintended operation.

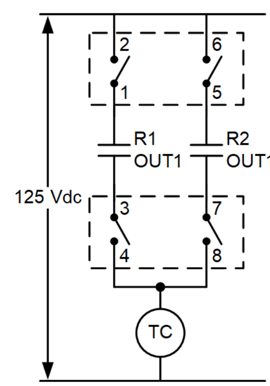

Figure 3 Two-Relay Scheme—Output Contacts From Redundant Relays Connected in Parallel

2) *Two-Relay Scheme—Relay Output Contacts Connected in Series:* In this two-relay scheme, R1 and R2 are two redundant relays and each relay has an output that is connected in series, as shown in Figure 4, to operate the circuit breaker. The circuit breaker operates only when both the relays assert their respective output contacts (OUT1). In this scheme, when a relay misoperates, it does not cause an unintended circuit breaker operation as the other relay would not have asserted its output, thus improving the security of the scheme. However, the dependability of the scheme deteriorates because the system is rendered inoperable when one of the relays is unhealthy.

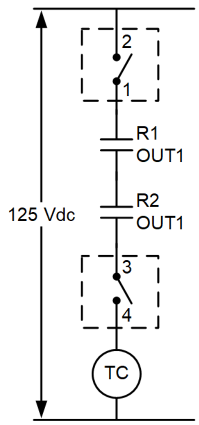

Figure 4 Two-Relay Scheme—Output Contacts From Redundant Relays Connected in Series

3) *Two-Relay Scheme—Relay Output Contacts Connected in Series With Error Logic Implemented Using Auxiliary Relays:* The loss of dependability in the two-relay scheme with output contacts connected in series can be mitigated by using an "error" logic that transforms the two-out-of-two scheme (output contacts from both relays need to assert to take a control action) into a single-relay scheme when one of the two relays becomes unhealthy, as shown in Figure 5.

In this two-relay scheme, external auxiliary relays are used to implement the error logic. In this scheme, a relay output is used to drive an auxiliary relay when the relay is healthy, as shown in Figure 6. In this example, the Relay 1 output (R1 OUT3) is used to drive an auxiliary relay (R1-EL) for error logic function implementation.

The relay output contacts OUT1 and OUT2 are functionally the same in both relays and can be programmed with the same relay logic. If the healthy status of the other redundant relay is monitored, either by using a contact from the auxiliary relay or directly from the redundant relay, then OUT2 can be programmed to functionally assert only when the other relay is unhealthy. Modern microprocessor-based relays perform self-checks to identify any relay hardware errors that can deem the relay unhealthy. The error logic output (R1 OUT3 in this example) can be programmed with the inverse of the Relay Word bit that represents a hardware error, thus asserting the output when the relay is healthy.

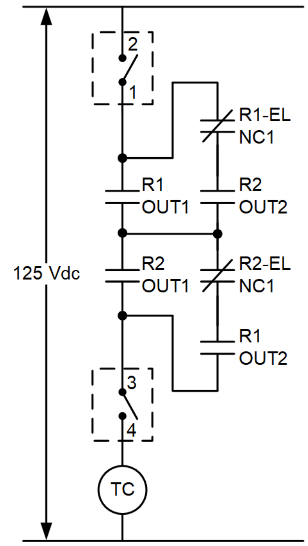

Figure 5 Two-Relay Scheme—Output Contacts From Redundant Relays Connected in Series With Error Logic Implementation

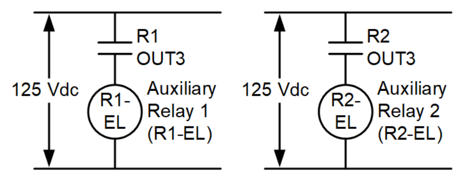

Figure 6 Two-Relay Scheme—Auxiliary Relay Control Circuit for Error Logic Implementation

A normally closed (NC) contact from the error logic auxiliary relay is connected as part of a parallel circuit, as shown in Figure 5, thus providing an alternate path when one of the relays is unhealthy. When the R1 relay is healthy, the NC contacts of the R1-EL auxiliary relay assert; hence, the NC contacts are open. Similarly, when the R2 relay is healthy, the NC contacts of the R2-EL auxiliary relay are open. Thus, when both relays are healthy, the control circuit operates on a two-out-of-two scheme. When one of the relays is unhealthy, the relay's error logic output (for example, R1 OUT3) does not drive its error logic auxiliary relay (R1-EL in this case). As a result, the NC contacts of the error logic auxiliary relay bypass the verification needed from the failed relay, thus transforming the scheme to a single-relay scheme. In this example, if the R2 relay were unhealthy, the R1 relay could operate the circuit breaker using two of its own output contacts (R1 OUT1 and R1 OUT2) in series with the auxiliary relay R2-EL NC1 contact. Though the auxiliary relays introduce additional points of failure, they enable the scheme to still be operational when one of the relays is unhealthy, thus improving the overall dependability of the two-relay scheme.

C. *Voting Scheme With Three Relays*

In a voting scheme, an odd number of relays receives the same analog and digital inputs from various sources and the majority of them need to perform a control action to operate the circuit breaker.

The reduction of security in the two-relay scheme described in Section II.B.1 and the reduction of dependability in the two-relay scheme described in Section II.B.2 are mitigated by using a voting scheme. Implementing a voting scheme increases both security and dependability, thus increasing reliability. Voting schemes are typically implemented using a three-relay scheme.

The following subsections discuss a few different methods of implementing voting schemes with three relays.

1) *Voting Scheme With Three Relays—No Error Logic:* A simple form of implementing a voting scheme is by designing a control circuit in which two of the three relays assert the same functional outputs to operate the circuit breaker, as shown in Figure 7.

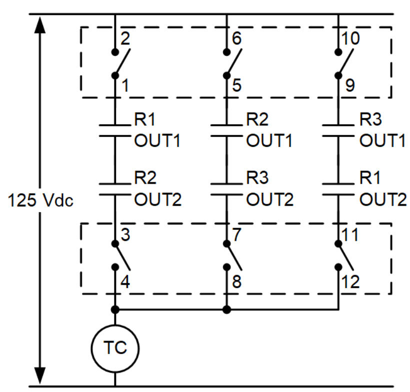

Figure 7 Three-Relay Voting Scheme

R1, R2, and R3 are three redundant relays, and each relay has OUT1 and OUT2 programmed to trip the circuit breaker. In this case, the circuit breaker is tripped open when at least one pair of OUT1 from one of the relays and OUT2 from another relay assert together.

When one of the relays is unhealthy, the scheme is still operable using the other two healthy relays. The security of the system is maintained as the other two healthy relays need to operate in unison for a control action. However, if two of the relays are unhealthy, the system becomes inoperable.

2) *Voting Scheme With Three Relays—Error Logic Implemented Using Internal Relay Logic:* If dependability is the highest priority when one or two relays are out of service or unhealthy, the two-out-of-three voting scheme can be transformed into an independent two-relay scheme (such as in Figure 3) or a single-relay scheme (in which each healthy relay can independently operate the circuit breaker) using error logic when any of the three relays becomes unhealthy, as shown in Figure 8.

In this scheme, NC output contacts from each relay are connected as inputs to every other healthy relay, as shown in Figure 9. Consider Relay R1 in this example. When the relay is healthy, it asserts the NC output contacts connected to the other relays (NC Output R1 OUT5 connected to the R2 IN2 input and NC Output R1 OUT4 connected to the R3 IN1 input for error logic implementation), thus opening these contacts. Each relay recognizes that the other relay is healthy if it reads logical 0 or unhealthy if it reads logical 1 in its error logic input. Hence, the R2 relay recognizes that the R1 relay is healthy when R2 IN2 is deasserted.

The relay internal logic is programmed to operate OUT1 and OUT2 when the other two relays are healthy (determined using IN1 and IN2 inputs) or operate OUT3 when one or both of the other relays are unhealthy. Hence, the system operates in a two-out-of-three voting scheme using OUT1 and OUT2 of the relays when all the relays are healthy and switches to an independent relay scheme using OUT3 when at least one of the relays is unhealthy.

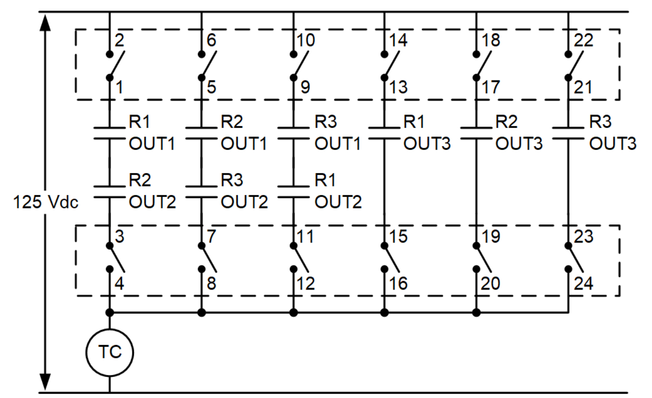

Figure 8 Three-Relay Voting Scheme—Error Logic Implementation Using Internal Relay Logic

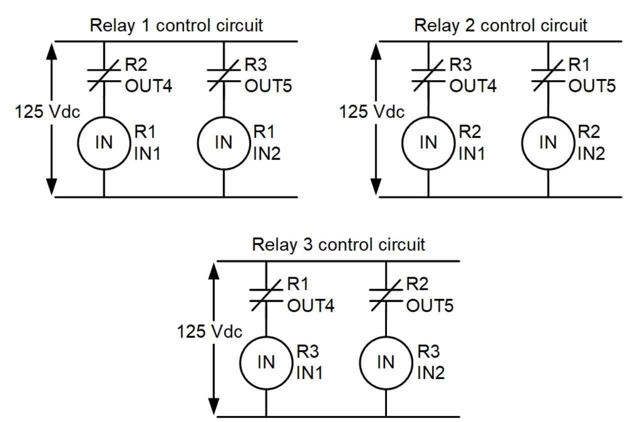

Figure 9 Three-Relay Scheme—Relay Control Circuit for Error Logic Implementation

This type of error logic implementation requires several spare outputs and inputs in each relay. However, if only a limited number of spare outputs is available, auxiliary relays can be used to reduce the number of outputs required or the error logic can be implemented as described in Section II.C.3.

3) *Voting Scheme With Three Relays—Error Logic Implemented Using Auxiliary Relays:* In this voting scheme implementation, external auxiliary relays are used to implement error logic. NC contacts from the error logic auxiliary relays are connected in parallel with the bottom rung of the output

contacts in the voting scheme, as shown in Figure 10. In this scheme, a relay output is used to drive an auxiliary relay when the relay is healthy, as shown in Figure 11.

In this example, Relay 1 Output R1 OUT4 is used to drive the auxiliary relay R1-EL for error logic implementation. When R1 is healthy, the NC contacts of R1-EL assert; hence, the NC contacts are open. Similarly, when R2 and R3 are healthy, the NC contacts of R2-EL and R3-EL are open. Thus, when all the relays are healthy, the control circuit operates as a two-out-of-three voting scheme. When one of the relays is unhealthy, the relay's error logic output (for example, R1 OUT4) will not drive its error logic auxiliary relay (R1-EL, in this instance). As a result, the NC contacts of the error logic auxiliary relay will bypass the verification needed from the other relay, thus transforming to an independent relay scheme. In this example when Relay 1 is unhealthy, R1-EL NC2 will bypass R3 OUT2 in the second pair and R1-EL NC1 will bypass R1 OUT2 in the third pair of the voting scheme, thus allowing either Relay 2 or Relay 3 to independently operate the circuit breaker without supervision from the other relays. In comparison to the scheme in Section II.C.2, the addition of the auxiliary relay presents additional points of failure, thus marginally reducing the dependability. However, it marginally increases security by eliminating the chance of misoperation of an additional output (OUT3 in any of the three relays in Figure 8).

4) *Application Considerations for Multirelay Schemes:* Depending on the application and the requirements, a combination of the schemes described in Section II.C.1–Section II.C.3 can be used. For example, for a feeder application with sensitive loads, the schemes detailed in Section II.C.2 and Section II.C.3 can be utilized for the tripping circuit in which dependability has the higher priority and the scheme detailed in Section II.C.1 can be utilized for the closing circuit. For an automatic transfer scheme application in which security is the higher priority, the scheme described in Section II.C.1 can be used for both the tripping and closing circuits.

Furthermore, in applications with automatic circuit breaker close operations, such as automatic transfer schemes, the choice of the scheme implemented needs to be carefully considered. The error logic can cause the healthy relays in the schemes in Section II.C.2 and Section II.C.3 to have independent control when one of the relays is unhealthy. A scenario in which the two healthy relays disagree with each other on the next automatic breaker operation (whether to open or close the circuit breaker) can lead to a situation in which one relay keeps closing the circuit breaker after the other relay keeps tripping the circuit breaker, thus damaging the circuit

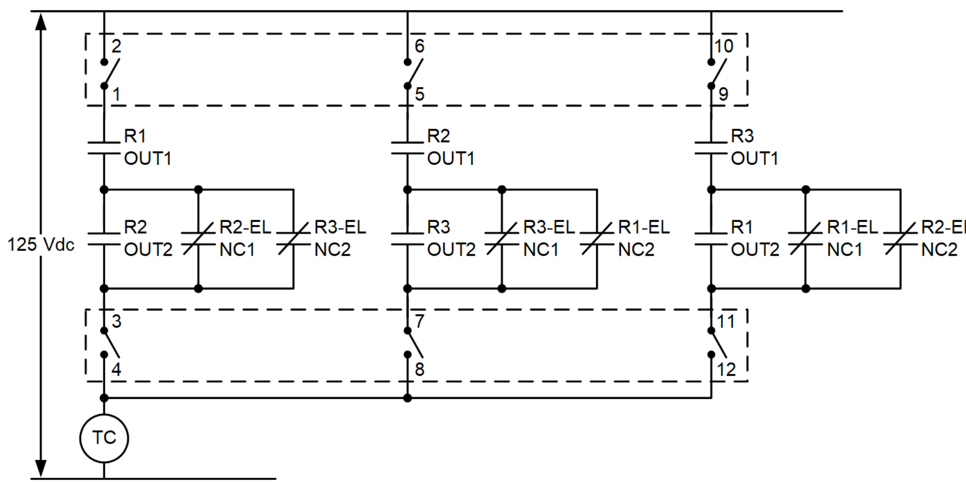

Figure 10 Three-Relay Voting Scheme—Error Logic Implementation Using Auxiliary Relays

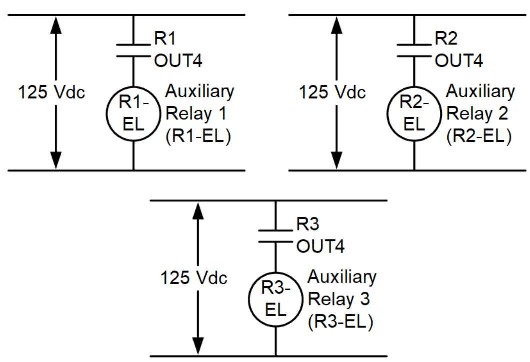

Figure 11 Three-Relay Scheme—Auxiliary Relay Control Circuit for Error Logic Implementation

breaker. The scheme in Section II.C.1, which does not have error logic, can be better suited for an application with automatic circuit breaker close operations to avoid such a scenario.

It is crucial that the protection and operation philosophies of the redundant relays be aligned and synchronized. Having different logic programming in redundant relays that do not align or synchronize with the system's operation philosophy can cause undesirable operations. A simple approach is to deploy identical logic programming in the redundant relays when the relays are alike.

Modern relays can have multiple output cards to expand the number of outputs available in the relay. In voting schemes, it may be beneficial to use outputs from different output cards of the relay in the control circuit rather than using outputs from the same output card. In a scenario when an output card fails, using outputs from different output cards of the relay shall result in fewer paths being lost in the voting scheme to perform the control action. For example, consider a relay with the outputs OUT301, OUT302, OUT303, and OUT304 in one output card in Slot C of the relay and OUT401, OUT402, OUT403, and OUT404 in another output card in Slot D of the relay. When the Slot C card of the relay fails, a voting scheme created using outputs from only the Slot C relay card (such as using OUT301 and OUT302) will result in the loss of two of the three paths for tripping the circuit breaker, whereas a voting scheme created using one output from the Slot C relay card and another from the Slot D relay card (such as OUT301 and OUT401) will result in the loss of only one path of the tripping circuit.

In multirelay schemes, it is critical to eliminate or minimize the communications dependency between the redundant devices. Communications dependency between devices can be detrimental to the dependability of the scheme. Hence, it is recommended to design and configure devices such that the control operation is not affected by the loss of communications between the relays. However, a lack of communications between redundant devices may require operational actions and commands, such as pressing a relay front-panel pushbutton, in each of the three relays. This may also need to be performed simultaneously depending on the application.

Another consideration is the use of test switches. It is a common practice to utilize test switches in the secondary current transformer (CT) and potential transformer (PT) circuits. Similarly, it is recommended to design the control circuit with test switches, as shown in Figure 2 to Figure 10. Though test switches in control circuits lead to additional cost and space requirements, test switches can isolate the relay control actions that can prevent relay misoperations during testing, commissioning, or maintenance. The use of a single or dual combination of test switches (test switches on one or both sides of the relay contacts) for control circuits depends on the degree of isolation desired.

D. Hardware Redundancy

1) *Battery and DC Source Redundancy:* The auxiliary dc control power is a vital part of the P&C circuit. It impacts critical functionalities, such as operating the circuit breaker, and supplemental devices, such as local and remote indications. The auxiliary dc control power system typically consists of a battery bank, battery charger, distribution system, switching and protective devices, and any monitoring equipment. Due to the importance of the auxiliary dc control power supply, dual systems can be installed to improve reliability, as shown in Figure 12.

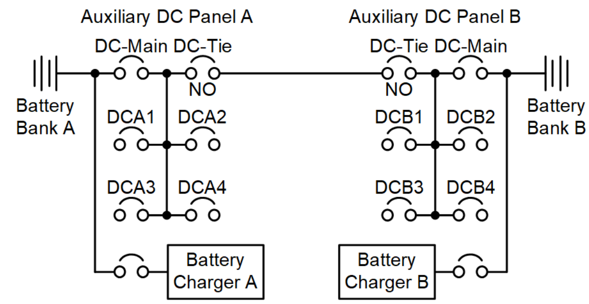

Figure 12 Example of Dual Auxiliary DC Control Power System

There are a few key design aspects that need attention when implementing a dual-battery system. The first consideration is appropriately sizing the components that make up the dc control power system. Each battery must be oversized such that a single battery system can sufficiently supply the loads of both systems. Next, in addition to a means for tying the two dc supply buses together, it is recommended to include means to isolate each battery. This will enable one set of batteries to be taken out of service for testing or maintenance while still supplying the loads. For example, in Figure 12, the main breaker in Panel B can be opened and the normally open (NO) tie breakers can be closed when Battery Bank A is required to feed both Panel A and Panel B. Similarly, in cases in which only a single battery system is used and a portable battery system is available as a backup, care should be taken in the design to have the means to isolate the station battery and connect the portable battery.

2) *Breaker Trip Coil Circuit Redundancy:* When the circuit breaker has more than one trip coil, the relay can drive each of these trip coil control circuits simultaneously or one after the other, thus improving dependability. The application of breaker trip coil circuit redundancy for a single-relay scheme is shown in Figure 13. The same concept can be extended to two-relay and three-relay voting schemes as well. Care should be taken while configuring the relay so that the redundant trip coils are actuated before the breaker failure scheme times out, when applicable.

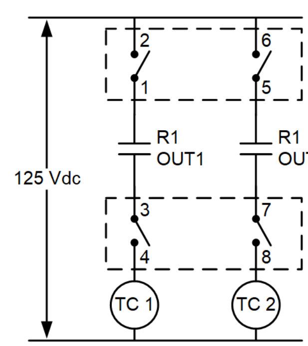

Figure 13 Control Circuit for a Breaker With Two Trip Coils

3) *Synchronism Check:* Checking whether two power sources are synchronized using the synchronism check function (ANSI device number 25) is an important part of transfer schemes and applications involving generation sources. In some cases, multifunctional relays are used for this purpose and have three-phase voltage inputs from one power source but only a single-phase voltage input from the other power source. Thus, the synchronism check is performed on only one phase of the system.

In applications with redundancy, such as two-relay or three-relay schemes, each redundant set of relays can perform a synchronism check on different phases to increase the reliability of the system. In Figure 14, Relay 1 performs a synchronism check in Phase A to neutral (V_{AN}) and Relay 2 with Phase B to neutral (V_{BN}) for wye-connected PTs.

4) *Breaker Status Input to the Relay:* Circuit breakers typically have 52a (contact is open when circuit breaker is open) and 52b (contact is closed when circuit breaker is open) contacts that indicate the circuit breaker status available for connection in P&C circuits and inputs to the relays.

As both 52a and 52b present the same type of information (circuit breaker status), only one of them is usually wired to the relay in most applications. In applications that are sensitive to the circuit breaker status, such as automatic transfer schemes, both 52a and 52b circuit breaker status inputs can be wired to the relay. The relay can be programmed to recognize any mismatch between the 52a and 52b statuses. This can help eliminate any misoperation due to an incorrect circuit breaker status input to the relay, which can arise in situations such as a loose wiring connection.

5) *Redundancy in Inputs to the Relay:* The control operations performed by the relays depend on the inputs received by the relays. Protection schemes based on inputs that are not very secure or dependable can utilize redundancy to increase the reliability of the protection scheme.

For example, transformer sudden pressure relays can misoperate [5]. A redundant scheme with self-latching is applied to the circuit design, as shown in Figure 15, to increase reliability. In this scheme, three sudden pressure relays are used. A contact from each sudden pressure relay that is near the transformer (hence the connections are shown using dashed lines) is wired to an auxiliary relay present at the switchgear (63-AR1, 63-AR2, and 63-AR3).

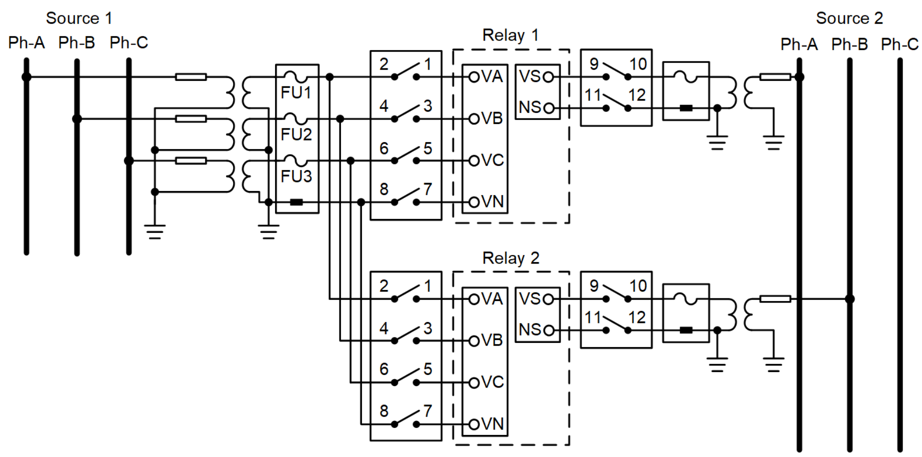

Figure 14 Synchronism Check—Relay 1 Utilizing V_{AN} and Relay 2 Utilizing V_{BN} for Synchronism Check

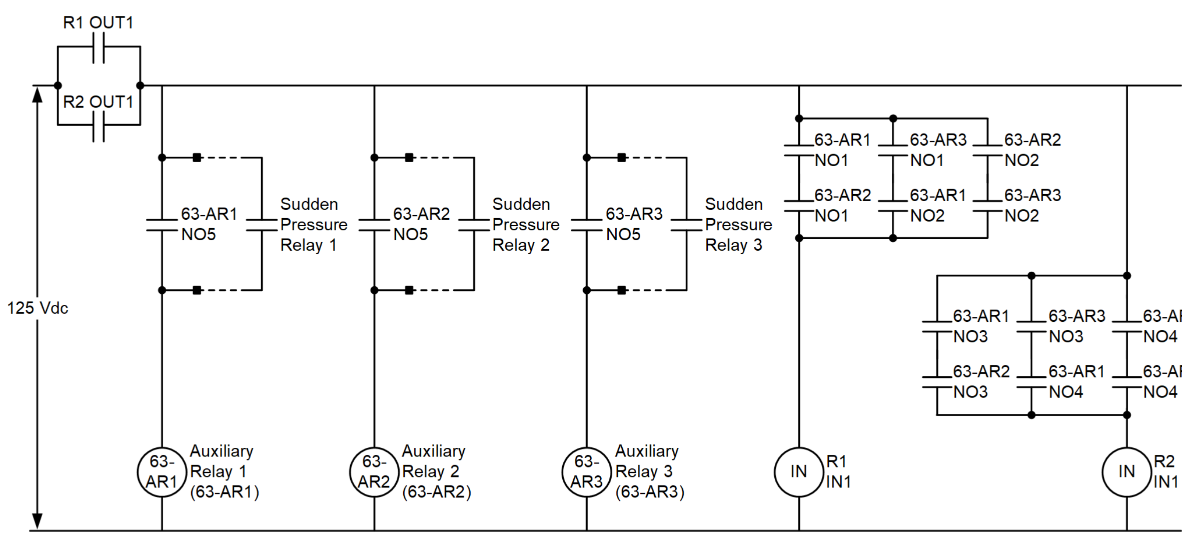

Figure 15 An Example of Control Circuit With Redundancy in Inputs to the Relay

Outputs from these auxiliary relays are connected in a two-out-of-three voting scheme in series to the digital relay input (R1 IN1). In this case, the relay receives a sudden pressure trigger at its input only if two out of the three sudden pressure relays detect an abnormal condition. The relay outputs R1 OUT1 and R2 OUT1 are closed when their respective relays are healthy. The auxiliary relays in this application are connected such that they remain latched when the sudden pressure relay asserts. The relay outputs R1 OUT1 and R2 OUT1 are programmed such that the outputs deassert and the contacts open when an operator acknowledges the sudden pressure relay trip (for example, by pressing a relay front-panel pushbutton or by using a human-machine interface). When these relay outputs open, it cuts off the dc control power supply to the auxiliary relays, thus unlatching the auxiliary relays.

III. CONCLUSIONS

P&C circuit design is a critical aspect of electric power systems as the operation of the power system depends on it. Hence, engineers seek to maximize the reliability of the P&C circuit while balancing the technical requirements and the cost. For this purpose, redundancy can be introduced in the P&C circuit design to improve security and dependability. The paper presents P&C circuit design of increasing redundancy and complexity, and the impact on reliability for each of these schemes is discussed. Table I presents a summary of the P&C circuit design schemes presented in this paper.

TABLE I
Summary of P&C Circuit Design Schemes Discussed in This Paper

Scheme	Relay Output Connections	Summary	Comments
Single-relay scheme	NA	Low dependability. Low security.	Scheme is inoperable when the relay is unhealthy.
Two-relay scheme	In parallel	Compared to single-relay scheme: Increase in dependability Decrease in security	Either relay can misoperate and cause an unintended operation.
	In series	Compared to single-relay scheme: Increase in security Decrease in dependability	Scheme is inoperable when one of the relays is unhealthy.
	In series with error logic	Compared to single-relay scheme: Increase in security Compared to two-relay scheme with outputs connected in series: Increase in dependability	Though additional points of failure are introduced by adding new devices such as auxiliary relays, this scheme provides the security offered by the two-relay scheme with outputs connected in series and is operable using the error logic when one of the relays is unhealthy.
Three-relay scheme	Voting scheme—no error logic	Compared to two-relay scheme: Increase in security Increase in dependability	The reduction of security in the two-relay scheme with contacts connected in parallel and the reduction of dependability in the two-relay scheme with contacts connected in series are mitigated by using a voting scheme. In a voting scheme, the control circuit is designed such that two out of three relays must perform the same control action to operate the circuit breaker.
	Voting scheme—error logic implemented using internal relay logic	Compared to two-relay scheme: Increase in security Increase in dependability	The three-relay scheme transforms from a two-out-of-three voting scheme into an independent relay scheme using error logic implemented with internal relay logic when one of the three relays becomes unhealthy. This type of error logic implementation requires several spare outputs and inputs in each relay.
	Voting scheme—error logic implemented using auxiliary relays	Compared to two-relay scheme: Increase in security Increase in dependability	The three-relay scheme transforms from a two-out-of-three voting scheme into an independent relay scheme using error logic implemented with auxiliary relays when one of the three relays becomes unhealthy. This type of error logic implementation is beneficial when a limited number of protective relay spare outputs are available compared to implementing error logic using internal relay logic.

IV. REFERENCES

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V. VITAE

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