A Practical Guide: Design and Protection Considerations for Developing Reliable Automatic Transfer Schemes (ATSs)

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A Practical Guide: Design and Protection Considerations for Developing Reliable Automatic Transfer Schemes (ATSs)

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***Abstract*—An automatic transfer scheme (ATS) is a widely used power system protection and control scheme to automatically transfer loads from one source to another during contingencies. Most modern ATS controllers and logic processors are also programmed with additional protection and operational functions that become sources of error when not applied properly in conjunction with the ATS. As a result, engineers face several challenges when dealing with such complex schemes. Therefore, this paper offers a step-by-step guide to developing reliable and secure ATSs, drawing from the authors' field experiences and lessons learned while implementing such schemes. The paper explains various factors and steps to consider when developing an ATS, including (i) the location of the scheme and appropriate transfer initiate conditions, (ii) loads connected directly to the buses in the ATS and criticality of the loads, (iii) various functions and operations included in the ATS, (iv) ATS switchgear design considerations, (v) power system protection considerations, and (vi) testing and commissioning of the ATS.**

I. Introduction

A transfer scheme is used in different switchgear configurations, such as main-tie-main, main-tie-tie-main, main-generator, and generator-generator, at various distribution voltage levels from 208 V to 34.5 kV to provide redundancy of power supply. Fig. 1 shows a simplified version of such a transfer scheme applied in a main-tie-main switchgear configuration wherein the logic for the automatic transfer scheme (ATS) is programmed in microprocessor-based logic controllers and relays. It consists of two normally closed (NC) incomer breakers and a normally open (NO) tie breaker. In normal conditions, both sources supply the loads connected to their respective buses and the tie breaker is open. In the event of the loss of Source 1, the NC Main 1 incomer breaker opens and the normally open tie breaker closes to transfer the load from one source to another. When the load transfer is performed automatically without any human intervention, it is commonly referred to as an ATS.

Apart from the primary function of automatically transferring loads from one source to another, most of the modern ATS logic controllers also have additional operational functions, such as retransferring the loads back when a healthy source returns, hot standby or retransfer inhibit to restore the load in a controlled manner, breaker failure detection, live-source seeking, emergency generator call, or black start. Moreover, these operational functions are combined with protection functions, such as arc flash, transformer or cable differential, fast bus tripping scheme, or directional protection, which add complexity to the overall logic.

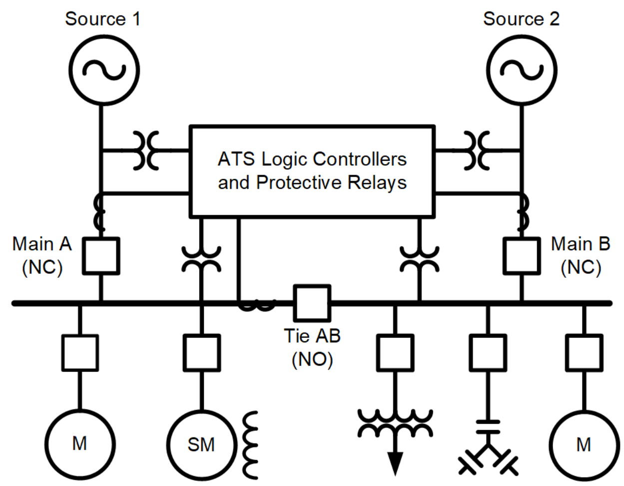

Fig. 1. Simplified one-line diagram for a typical ATS.

In practice, the implementation of such complex schemes is challenging due to:

- A lack of standard industrial practices and guides.

  Most of the industrial facilities tend to have their own sets of design and operational philosophies for the ATS.
- Involvement of multiple entities, engineering firms, and device manufacturers.

  The development and implementation of an ATS could involve (i) protection and control (P&C) design engineers for designing the switchgear and programming of logic, (ii) power system study engineers for performing protection coordination studies, (iii) automation engineers for integrating remote control and monitoring functions, and (iv) plant operators or owners who decide the operation philosophy. The lack of alignment between various engineers across the different disciplines can lead to sources of errors.

  For example, a switchgear designer may not be aware of the plant operation philosophy or the different functions that will be programmed in relays and the logic controller, and hence, may not provide the required inputs or outputs to the controller device.

- Multiple different schemes present in a single industrial facility.

  For example, a protection engineer working on a low-voltage (LV) ATS may not be aware of the impact of the upstream medium-voltage (MV) switchgear design on the LV ATS, such as any hardwired interlocks or communications-assisted transfer schemes.

- Limited availability of a complete system to perform comprehensive testing and commissioning.

  An inability to thoroughly test the ATS operation during the initial commissioning can lead to errors down the line.

  For instance, in brownfield or retrofit projects, it may not be feasible to schedule a complete plant outage. This could result in performing partial or simulated testing without considering the impact of upstream or downstream devices on the ATS, limiting the ability to identify potential errors.

The following are some of the common causes of errors.

- Protection zones and elements are not clearly defined in conjunction with the ATS.

  When protection functions are not clearly defined to either allow or block a transfer operation, it could lead to misoperations.

  For example, a downstream fault detected using a standard time-overcurrent element may need to block ATS operations, whereas an upstream fault detected using a cable or transformer differential need not block ATS operations. More such protection-related cases are discussed in Section VIII (Step 5).

- A transfer does not take place when it is supposed to.

  ATS logic tends to have conditions defined that initiate transfer operations and block automatic operations in various circumstances. A common reason that a transfer may not occur could be because the transfer initiate and transfer blocking conditions were not correctly defined to allow and block transfers accordingly.

- Transfer time is longer than desired.

  The intent of an ATS is to restore the power back to the loads with as small a time delay as possible. When the ATS is not carefully designed considering the rest of the system surrounding the ATS, it may prolong the restoration time. For instance, a scenario that can affect the transfer time occurs when the bus voltage takes longer to decay due to motor loads connected to it.

- Broken sequence of operation.

  When an operation sequence for an automatic transfer gets interrupted, the system may not complete the rest of the sequence and could get stuck or misoperate. This is common in an ATS in which multiple devices are connected with each other via a hardwired or communications interface. An example is an ATS with an emergency generator or black-start sequence associated with it that requires extensive signal exchanges among different devices. The transfer sequence here can be broken due to a loss of communication or generator system failure.

- Communications failure between devices or communications latency occurs.

  Most ATSs use communications channels between the devices for their operation. The means and medium of communications must be carefully designed to perform a transfer within a stipulated time. A network with heavy traffic or one in which signals need to pass through multiple devices to reach their destination can cause a transfer to fail or be delayed due to communications latency. This can occur in a large industrial system in which the ATS operation is dependent on common network switches for transfer trips or initiate conditions.

- Operator-related errors.

  Careful consideration while designing and programming the relay logic can help mitigate accidental errors caused by or impacting the safety of the operator. For example, operators may inadvertently trip an ATS breaker, in which case the ATS can lose loads instead of returning to its normal configuration if it is in automatic mode.

- The system was not designed for testing or maintenance.

  In some facilities, ATS operations may be infrequent events. Therefore, after an extended period since the ATS was commissioned, the system may not be functional, and its issues may go unnoticed until an ATS operation is necessary and the scheme has failed. If the system is designed to be testable and allow for maintenance to be performed as needed without impacting the loads or requiring an outage, this type of error can be avoided.

References [1] to [5] discuss the application of such schemes in detail. While this literature explains and provides details about an individual scheme and preprogrammed hardcoded logic, these do not cover the scheme implementation from a power system perspective.

Hence, to address the aforementioned challenges and to develop a robust ATS, this paper provides step-by-step guidance and recommendations based on field experiences and lessons learned while implementing such schemes. The paper is intended for design engineers creating the system as well as protection engineers developing the ATS logic. This paper provides engineers a cautionary reminder of the various sources of errors as well as guides them to avoid unnecessary mistakes to create a dependable and secure scheme. This paper does not discuss product-specific ATS logic or motor bus transfer schemes.

II. Commonly Used Terms

- Transfer operation

  A transfer operation is typically an operation in which a load is transferred from its primary intended source to an alternate source.

- Retransfer operation

  A retransfer operation is typically an operation in which a load is brought back to its primary intended source from an alternate source.
- Open-transition operation

  During the load transfer from one source to another, the breaker connected to the first source must be opened before the alternate source breaker is closed. Hence, both source breakers are open at the same time during the transfer process, and at no point are both sources connected (or paralleled) together.
- Closed-transition operation

  When transferring loads from one source to another, the breaker connected to the alternate source is closed before opening the breaker of the first source. Hence, both sources are connected together (or paralleled) for a predetermined period of time.
- Residual transfer

  This is one of the open-transition methods to transfer loads from one source to the other wherein an NC breaker is opened first before closing the new source breaker. The closing of a new breaker is supervised by a voltage condition to make sure the bus voltage falls below a certain threshold.
- Motor bus transfer

  When a bus primarily feeds motor loads, careful consideration is required when transferring the motor loads from one source to another. This type of transfer is known as a motor bus transfer. References [6] to [10] offer detailed information about motor bus transfers and considerations.
- Communications-assisted transfer

  In a communications-assisted transfer, a communication signal arriving from another device triggers a transfer in the ATS. The communication signal can be sent from other devices for various situations.
- Generator black start

  Emergency generators are commonly used in industrial facilities as a backup power source, to be used only when the primary utility supplies are lost. The process of turning on the generator source and making a power source available from a complete outage is known as a black start.

III. Step-by-Step Method

A step-by-step method to develop a reliable and secure ATS is presented in this section. It is presumed that an ATS has been chosen as the appropriate scheme for a specific part of the system. Selecting an ATS as the appropriate scheme is a critical step and may involve a detailed analysis of the power system, end user application, and its requirements, as well as system studies. However, this step is beyond the scope of this paper. Each of the steps listed here is explained in detail in the following sections.

Step 1: Identify the location of the scheme, and determine the transfer initiate conditions.

Step 2: Define the loads connected directly to the bus, and decide the type of transfers.

Step 3: Define the different functions to be programmed.

Step 4: Based on the requirements mentioned in the previous steps, select the design.

Step 5: Ensure protection considerations and coordination.

Step 6: Test and commission the system.

To explain these steps, a typical industrial power system with various ATS implementations at different parts of the system is considered in Fig. 2 and their associated tier numbers are summarized in Table I. The different parts of the figure are explained in Section IV (Step 1).

An ATS is categorized as a Tier 1 ATS when it is directly fed from the primary source, which can be either a utility or a generator source. The primary source can supply the ATS directly or via equipment such as a transformer but not via another upstream ATS. For example, ATS 1 and ATS 3 are categorized as Tier 1 ATSs. The utility source is the primary source for ATS 1, and the generator source is the primary source for ATS 3. When an ATS is fed by another ATS, it is considered as another tier in this paper. Here, ATS 4 and ATS 6 are considered Tier 2 ATSs as AST 4 is fed by ATS 1 and ATS 3, and ATS 6 is fed by ATS 1 and ATS 2. Similarly, ATS 5 is regarded as another tier (Tier 3) as ATS 5 is fed by ATS 4.

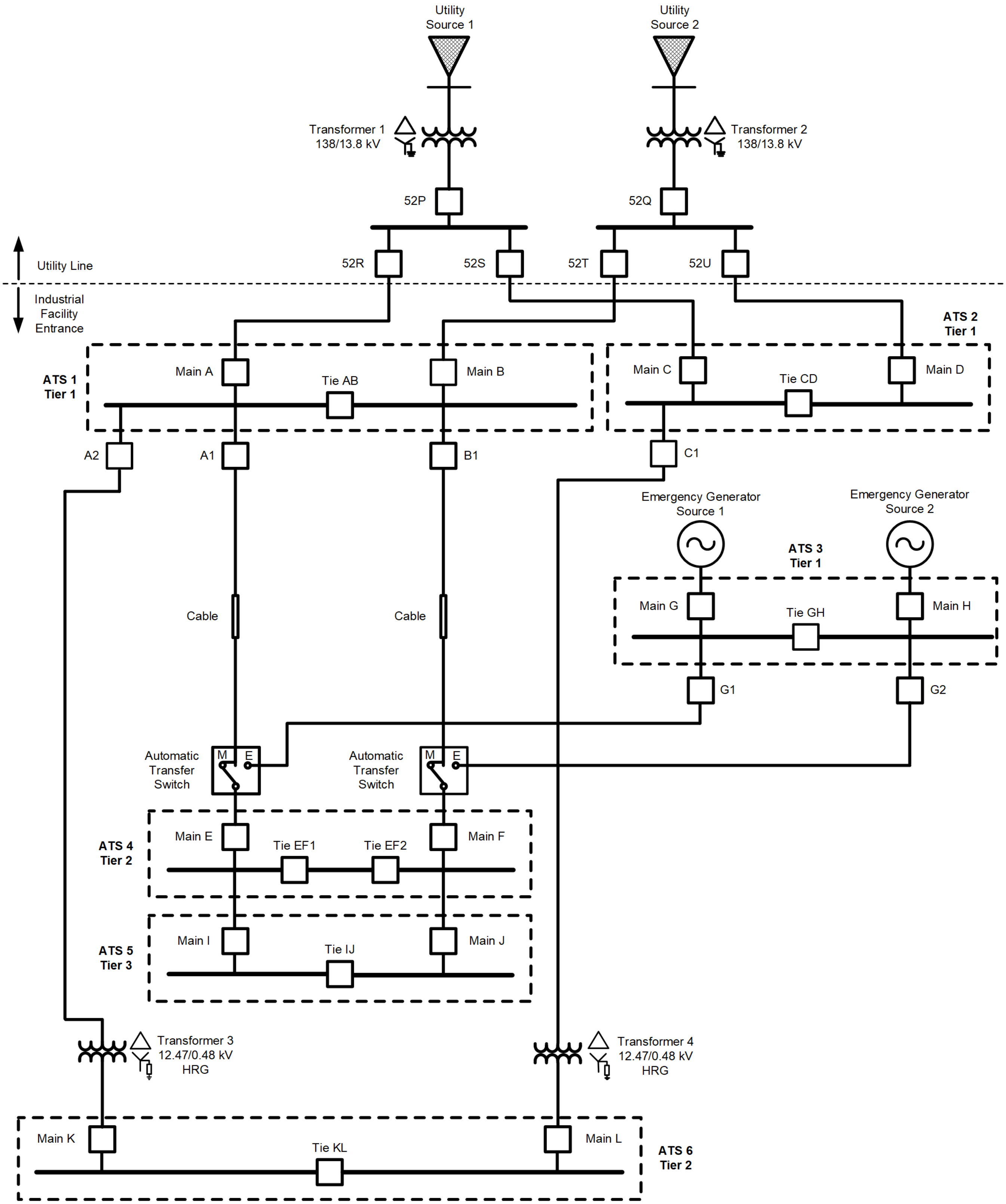

Fig. 2. A typical power system one-line diagram for industrial facility with multiple ATSs.

TABLE I
ATS CLASSIFICATION BASED ON LOCATION

ATS Number	Source	Tier Number	Other Parallel Transfer Schemes Fed by the Same Source
ATS 1	ATS connected to utility source, fed from transformer	Tier 1	1
ATS 2	ATS connected to utility source, fed from transformer	Tier 1	1
ATS 3	Directly fed from generator	Tier 1	0
ATS 4	From upstream transfer scheme	Tier 2	1
ATS 5	From upstream transfer scheme	Tier 3	0
ATS 6	From upstream transfer scheme, fed from transformer	Tier 2	1
ATS 7	ATS for backup emergency generator with black-start logic	NA	0
ATS 8	ATS for backup emergency generator with black-start logic	NA	0

IV. STEP 1: IDENTIFY THE LOCATION OF THE SCHEME

The first step in developing an ATS is to identify the location of the scheme in the power system. The location of the ATS helps in determining transfer initiate conditions, protection zones, and transfer initiate time. Largely, the ATS can be divided into the following categories:

- ATS directly connected to the utility source
- ATS fed by an upstream ATS
- ATS fed from a step-down transformer within the same facility
- ATS connected to an emergency generator source or distributed generation source

The transfer initiate conditions typically used based on the location of the ATS in the power system are described in this section.

A. ATS Directly Connected to the Utility Source

1) Power System Feeding the ATS

In this configuration, the main ATS incomer breakers are directly supplied by the utility lines as the primary source of power via direct incoming lines or a substation step-down transformer. This type of ATS is shown in Fig. 3 and is referred to as a Tier 1 ATS in this paper.

2) Transfer Initiate Conditions

When the main incomer of an ATS is directly fed by a utility source, the automatic transfer initiates only for a true loss-of-source condition. The ATS rides through momentary sag conditions for faults on the transmission line network.

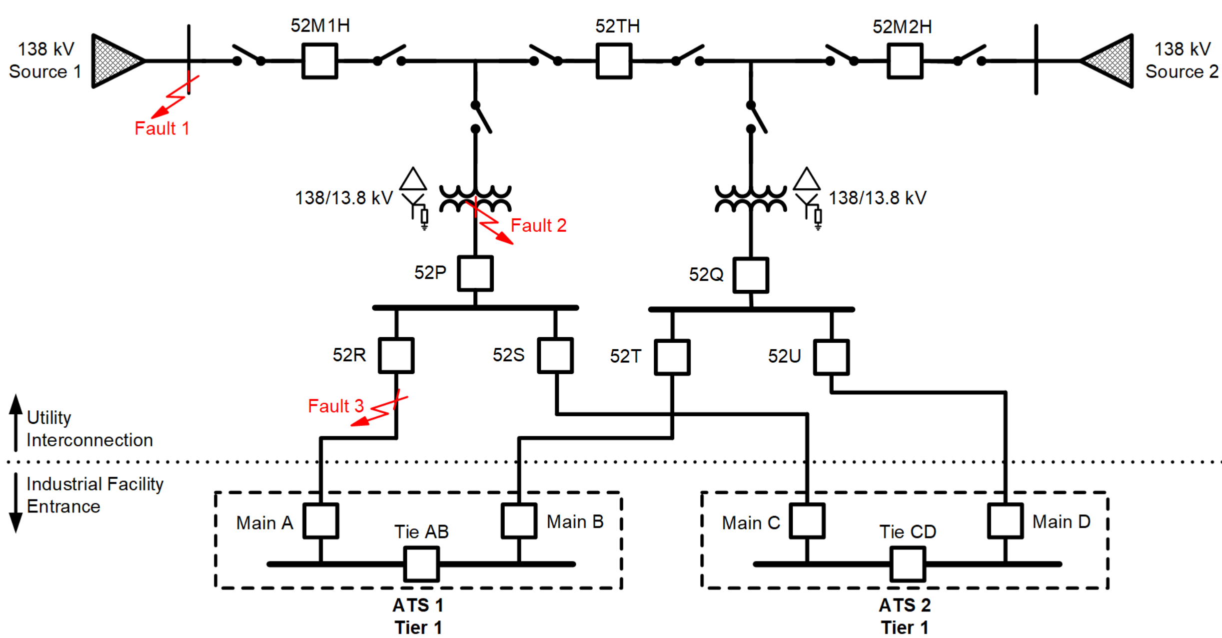

Fig. 3. ATS connected directly to utility.

For Fault 1 in Fig. 3, the ATS controller will experience a momentary decrease in the source voltage during the fault and then restores back to nominal voltage once the fault has been cleared by the protective device at the transmission level. This voltage dip is typically short and lasts for a few cycles depending on the location of the fault but should not cause the ATS to initiate an automatic transfer inside the industrial facility. References [11] and [12] provide more information about the impact of utility voltage sag on industrial facilities.

Sensitive loads, such as motor contactors, adjustable-speed drives (ASDs), data-processing equipment, programmable logic controller, and high-intensity discharge lamps, are often supported by uninterrupted power supply (UPS), synchronous condensers, capacitor banks, or constant voltage transformers to ride through short-term voltage sags. However, it is worthwhile to discuss the strategy for sensitive equipment with the end user to determine the ATS initiate conditions.

An ATS will perform an open-transition transfer after ensuring that the incoming source is lost, i.e., by ensuring the undervoltage is below the threshold level. However, this transfer time delay can be reduced by using communications-assisted transfer initiate signals that inform the ATS that its incoming source is lost.

In this case, ATS 1 should also initiate a transfer for any faults between the utility and ATS incomer such as Fault 2 and Fault 3 in Fig. 2. This can include a transformer fault (Fault 2, which would open 52P), a bus fault (a bus lockout can be triggered that trips 52P, 52R, and 52S), or a feeder fault (Fault 3, which would trip 52R). A communications-assisted transfer can also be initiated at ATS 1 when the upstream breakers (52P and 52R) are manually opened.

When multiple ATSs transfer at the same time to an alternate source, care should be taken when considering the inrush current on the transformer (discussed in Section VIII [Step 5]) and relay coordination to analyze the impact of these transfers on the system. For example, for a fault on Substation Transformer 1, such as Fault 2, or a bus fault on the bus connecting 52P, 52R, and 52S, the communications-assisted transfer will attempt to transfer multiple ATSs at the same time (here, ATS 1 and ATS 2) to Transformer 2.

An effective way to mitigate this challenge is to stagger the transfer initiate timings along with the loss-of-source supervision. Fault scenarios and breaker operations that would result in one or only a few ATSs transferring can be programmed with minimal time delays for a communications-assisted transfer. In this paper, we refer to this as a "fast automatic transfer." For ATS 1, this includes Fault 3, and manually opening breaker 52R for transferring loads from Transformer 1 to Transformer 2. Similarly, ATS 2 can also perform a fast automatic transfer for a fault between 52S and Main C or when the 52S breaker is manually opened.

For fault scenarios such as a transformer fault (here, Fault 2) or a bus fault on the bus connecting 52P, 52R, and 52S or manually opening 52P breaker, ATS 2 can be programmed to perform a communications-assisted transfer with some delay compared to ATS 1. In this paper, we refer to this as a "staggered automatic transfer."

In addition, a slower "residual automatic transfer" based on three-phase undervoltage is typically used where the installation of communications channels or hardwired transfer initiate signals are not possible or as a backup when the communications channel has failed. The residual transfer timing is set longer than the slowest fast automatic transfer and staggered automatic transfer.

A key component that allows communications-assisted transfers to be faster than residual transfers is the confirmation of the upstream breaker being open with the presence of a fault (if any), which ensures that the source to the ATS is lost. Otherwise, it is recommended to wait for a certain period to ensure the true loss of source when a transfer is initiated based only on undervoltage measurements. This prevents having to perform transfers for false positives on the loss of source caused by disturbances arising from surrounding system impact. Hence, the operating time for residual transfer would be longer than standard breaker operating times. For example, for a fault in ATS 2 that causes a sag in voltage measured at ATS 1, as both are fed by the same sources, the residual transfer time should be programmed with enough delay to allow sufficient time for the surrounding system breakers to operate and for the system (Source 1 voltage) to recover.

Note that the fast, staggered, and residual automatic transfer terms used here are different from the fast, in-phase, and residual automatic transfer terminology commonly used in motor bus transfer applications.

Table II presents an example of transfer timings for the different types of transfers discussed previously for ATS 1 and ATS 2.

TABLE II
EXAMPLE TRANSFER INITIATE TIME DELAYS FOR ATSS CONNECTED TO THE UTILITY SOURCE

	Fast Automatic Transfer	**Staggered Automatic Transfer**	**Residual Automatic Transfer**
ATS 1	20 ms	20 ms	500 ms
ATS 2	20 ms	250 ms	500 ms

B. ATS Connected to Upstream Automatic Transfer Scheme

1) Power System Feeding the ATS

In this configuration, the transfer scheme is subfed from another transfer scheme. A key benefit of this topology is that it allows the scheme to be tested regularly and for maintenance to be performed while minimizing the risk of dropping the loads or requiring an outage. For example, consider the loads connected to Tier 2, ATS 6 in Fig. 2. By having the loads of ATS 6 fed via Main L, testing and maintenance can be performed on Tier 1, ATS 1; Breaker A2; and Transformer 3 without impacting the loads on ATS 6.

2) Transfer Initiate Conditions

In a multitier ATS system such as the one shown in Fig. 4, the upstream ATS is programmed to transfer before the downstream ATS. For example, for a loss of source on Main A of Tier 1, ATS 1, Main E of Tier 2, ATS 4 would also experience a loss of source. ATS 1 operates first and the downstream ATS 4 detects the source voltage return as soon as ATS 1 completes the transfer. However, if ATS 1 fails to complete an automatic transfer due to either a Main A breaker trip failure, Tie AB breaker close failure, or ATS 1 being in manual mode, then ATS 4 needs to perform a transfer operation.

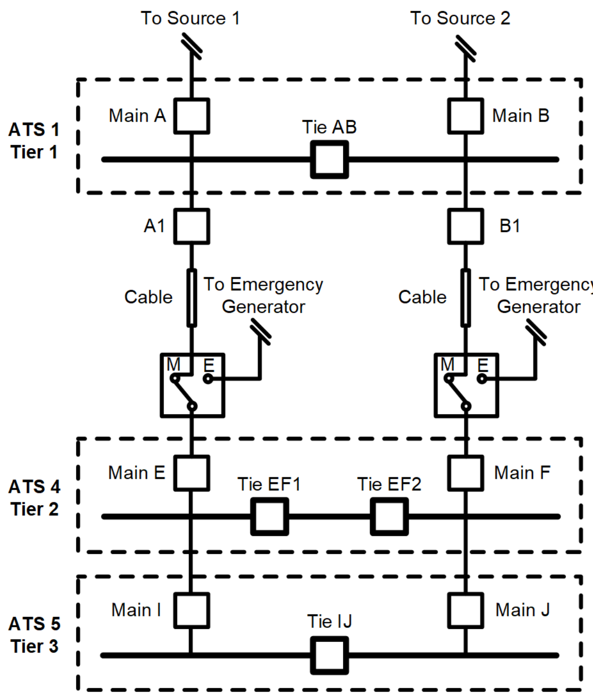

Fig. 4. Transfer initiate conditions for ATS connected to upstream ATS.

To accommodate the transfer timing of the upstream ATS, the residual automatic transfer of the downstream ATS needs to be programmed with a transfer initiate time delay upon measuring the undervoltage for a loss of source as shown:

Tier 2 ATS time delay > operating time of the slowest upstream ATS + time required to declare the ATS failure + communications latency (if applicable) + safety margin

In our example system, the slowest operating time of Tier 1, ATS 1 in Table II is 500 ms. Assuming the time to determine ATS failure depending on the breaker operating time is 250 ms, a communications latency time of 50 ms, and a safety margin of 150 ms:

Residual automatic transfer for Tier 2 ATS > 950 ms (500 ms + 250 ms + 50 ms + 150 ms)

Similar calculations can be performed for Tier 3, ATS 5 as well. Additionally, when the Tier 1 ATS fails, a signal can be sent to Tier 2 to instruct it to perform a fast automatic transfer to reduce the transfer initiate time.

Table III presents an example of transfer timings for the different types of transfers discussed previously.

TABLE III
EXAMPLE TRANSFER INITIATE TIME DELAYS FOR MULTITIER ATS

	Tier	**Fast Automatic Transfer**	**Residual Automatic Transfer**
ATS 1	Tier 1	20 ms	500 ms
ATS 4	Tier 2	20 ms	1 s
ATS 5	Tier 3	20 ms	1.5 s

C. *ATS Feeding From Step-Down Transformers*

1) *Power System Feeding the ATS*

Within the industrial facility, an ATS can be supplied from a step-down transformer wherein the low-side breaker of the transformer is also an incomer breaker for the ATS. As shown in Fig. 5, the incomer breaker Main C is part of the ATS and is also the low-side breaker of the transformer.

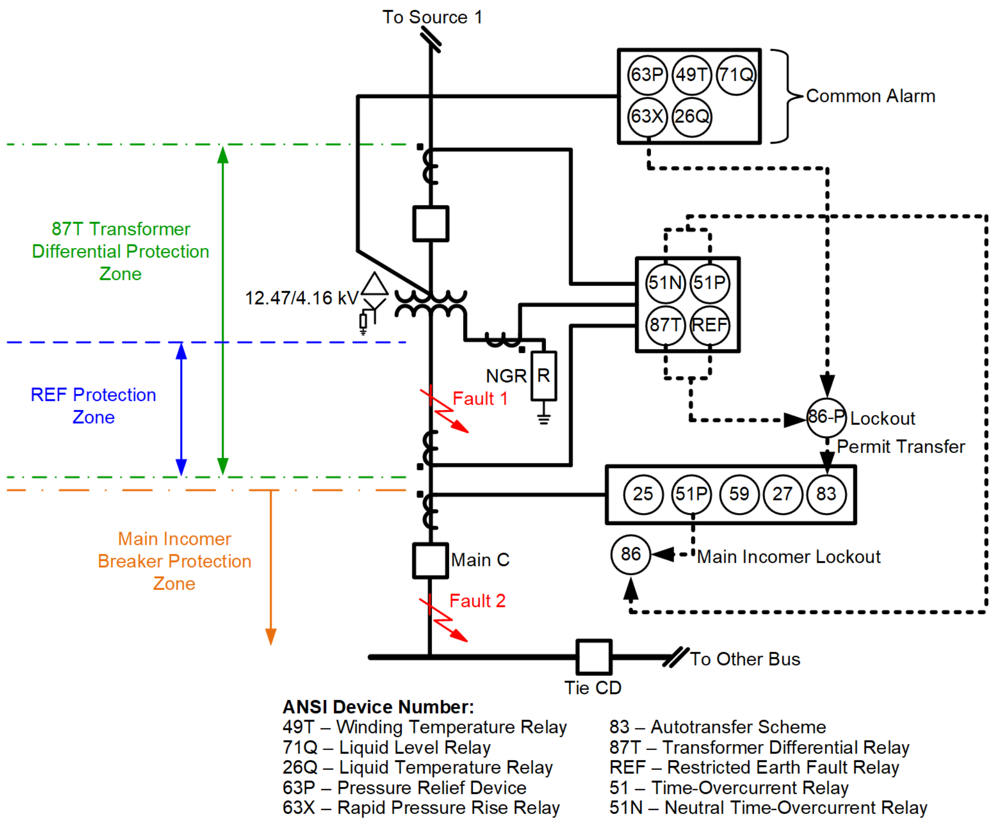

Fig. 5. Transfer initiate conditions for ATS feeding by a step-down transformer.

2) Transfer Initiate Conditions

The transfer initiate conditions in such cases are determined by the zone of protection and the fault-clearing time. The ATS will initiate a transfer for transformer faults, such as a transformer differential (87T), restricted earth fault (REF), or rapid pressure rise relay, if the low-side transformer current transformer (CT) does not have an overlapping zone with the main incomer. As elements like 87T and REF operate very fast, the assertion of backup overcurrent elements, such as time-overcurrent (51P and 51N), indicates a downstream fault toward the bus (such as Fault 2) and blocks the transfer. However, if the low-side transformer differential CT has an overlapping zone, the transfer would either be blocked or require an additional supervision of arc flash or bus differential to determine the location of the fault above or below the incomer breakers. Different variations of ATSs with transformer and bus protection zones are discussed further in [13] to determine the transfer initiate and blocking conditions.

D. ATS Connected to Distribution Generators or Emergency Generator Sources

1) Power System Feeding the ATS

In industrial power systems, emergency generators are used as a backup to supply power to critical loads. In Fig. 6a, G1 to G7 represent the probable locations of the generators as a part of the ATS. An emergency generator breaker (G1 or G4 generator) can be connected directly to the same bus of a primary ATS. The ATS can also be fed from an upstream generator bus system (G2, G3, G5, or G6 generator) or via an additional tie breaker (G7 generator). In another instance, shown in Fig. 6b, a separate two-breaker automatic transfer switch is also commonly used to transfer the loads from the utility to the generator.

Fig. 6a

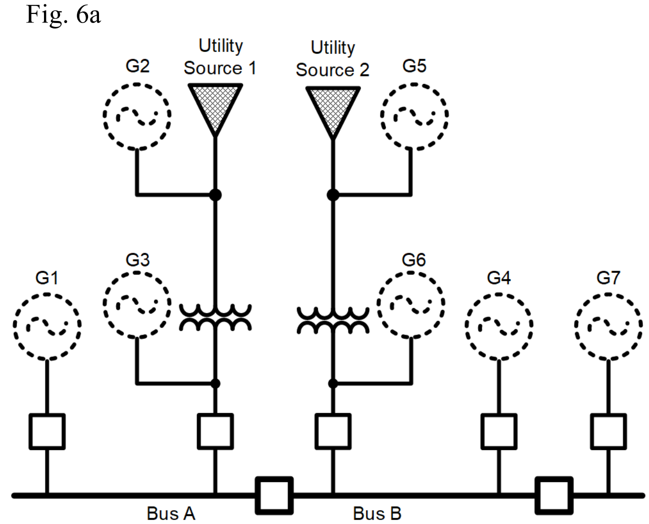

Fig. 6b

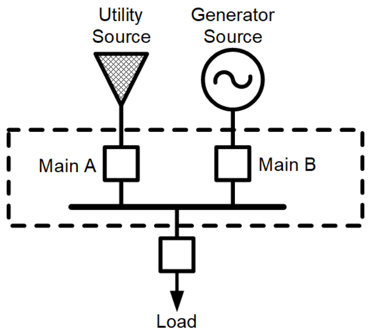

Fig. 6. a) ATS arrangements with emergency generators and b) automatic transfer switch.

2) *Transfer Initiate Conditions*

When the primary source comes from the utility and the generator system is the backup power source, transferring loads from the main utility source to the backup generators could involve several steps. For example, if the generators are directly connected to the bus or to the upstream transformers, the ATS controller calls for the generator when it detects a transfer failure to the alternative primary utility source. Typically, a communications-based channel is used to call the generator or initiate the black-start sequence due to the physical distance between the generator controllers and ATS controllers.

The following is an example of a typical sequence of operation.

1. The ATS controller identifies the transfer scheme failure.
2. The ATS controller sends a generator start or call command to the genset controller.
3. A transfer inhibit signal is applied to block the loads from transferring to the generator source.
4. The ATS system waits for the stabilizing signal to ensure the generator source is healthy.
5. The transfer inhibit is removed to transfer the loads to the generator source in a controlled manner.

For the other variation of an ATS configuration in which the primary source of power is distributed generators, as shown in Fig. 7, the transfer initiate conditions should be coordinated with the undervoltage protection elements of the generation system. For example, motor loads directly connected to a distributed generator source can cause a voltage drop at ATS for a prolonged period. Hence, the transfer initiate voltage needs to be set below this voltage drop level, and the time delay should be greater than the time delay set in the generator protective relay.

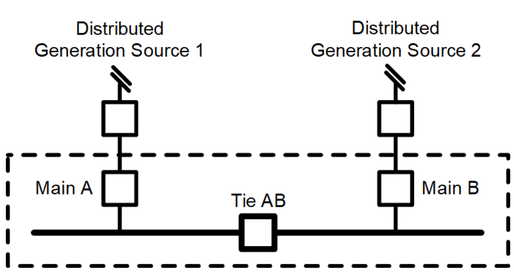

Fig. 7. ATS connected to distribution generators.

V. Step 2: Define the Loads Connected Directly to the Bus and Criticality of Loads

The automatic transfer time and voltage conditions for transfer initiate also depend on the type of loads and criticality of the loads directly connected to the bus. The impact of different types of loads connected directly to the ATS bus is discussed in this section. The required type of transfers can be determined based on the loads connected to the bus.

A. *Direct Online (DOL) Motor Loads*

Induction and synchronous motors are among the most common loads in industrial facilities. When these motors are directly connected to the ATS bus, the bus voltage and frequency decay gradually if the power supply is lost. If the transfer of a power source for such loads is not supervised with specific voltage and frequency conditions, the motors can suffer mechanical damage due to sudden transient torque. This situation can be confusing for those unfamiliar with the system, as it may not be clear whether the bus should be considered a motor bus or not. The bus voltages are only affected by the terminal voltage of the motors if they are directly connected online. However, if the motors are started using drives or connected downstream of the transformer, the bus voltage for the ATS will not be affected.

The strategies to safely transfer motor loads from one source to another for in-phase, fast, and residual transfers are discussed in [8]. Overall, the combined impact of motor size, loads, inertia, and the number of induction and synchronous motors directly connected to the bus affects the frequency and voltage decay of the bus. In-phase and fast transfers may require detailed dynamic studies or a spin-down test of the motor bus to achieve a closed-transition transfer. Reference [14] provides details of the parameters required to perform such a study.

In order to ensure a safe transfer on residual voltage, the new power source's breaker should only be closed once the dead bus condition of 0.25 pu is achieved. Relying solely on a time-based transfer is not recommended. It is also important to note that the ATS controller or relay should accurately detect the undervoltage set point at low frequency to meet the acceptable limit of 1.33 pu for the V/Hz criterion. One way to validate the accuracy of the undervoltage element is to perform secondary injection ramp testing for V/Hz.

B. *ASDs*

IEEE-1566 [15] describes the details of an ASD response during a voltage sag and a loss-of-source condition.

As per the standard, ASDs are generally designed to ride through momentary sag conditions during external fault conditions. In certain applications where high-inertia loads are connected, they can extract the energy from the rotating system to feed the direct current (dc) bus capacitors and maintain the operation during very brief power outages.

During complete loss-of-source voltage, the drive system can withstand a 100 percent loss of voltage for 2 seconds or longer without losing control capability.

In both these situations, the ATS transfer time coordination is required to maintain the continuity of the motor operation without having to restart the motor loads. The shorter time delay and use of fast transfer in cases where motors are connected using ASDs benefits the scheme.

C. Capacitor Banks

Capacitor banks are used in MV switchgear to provide power factor correction and are often used in parallel with induction motor during motor startup.

During ATS operation, upon loss of supply, the capacitor banks are programmed to disconnect to avoid catastrophic failure of the circuit breaker due to trapped charges. The undervoltage relay is programmed to open the breaker during ATS operation. The time delay for this undervoltage relay needs to be coordinated with the transfer time.

D. Critical Life Safety Loads

The time duration and detailed operation logic for the ATS are sometimes governed by the loads it is serving. For example, critical life safety loads, such as fire pumps and hospitals, are governed by NEC standard, which requires the ATS to operate within a certain time period.

VI. Step 3: Define the Different Functions to Be Programmed

This section presents some of the additional functions that can supplement the ATS. These functions are programmed in conjunction with other conditions that supervise a breaker trip or close operation (for example, voltage condition checks for closing a breaker, such as live line-dead bus, or synchronism checks) and are not bypassed.

A. Brownout Condition

When the voltage on both the sources is below the nominal level that is considered a healthy voltage, brownout logic in which both the main breakers are tripped can be implemented.

This can be used to protect the loads, especially when the voltage is not healthy but is also not low enough to consider the source to be dead, so no other action can be taken. In addition, tripping both the main breakers allows the lower tiers of ATSs to perform a transfer and seek an alternate source.

For example, consider Tier 1, ATS 1 and Tier 2, ATS 4 in Fig. 2, which considers 90 percent of nominal voltage (Vnom) as healthy voltage and considers a source dead when the voltage level falls below 25 percent of Vnom. If a scenario in which the source voltage at both Main A and Main B is 70 percent of Vnom, the sources are neither healthy nor dead. The A1 and B1 feeders are also supplying Tier 2, ATS 4 at an unhealthy voltage, thus preventing the Tier 2 ATS from seeking an alternate source (i.e., the emergency generator source) as its sources are not dead.

Here, brownout logic can be implemented in Tier 1, ATS 1 that trips both Main A and Main B when both sources are below 80 percent of the Vnom. In this scenario, when both Main A and Main B are open, this results in both Main E (supplied by the A1 feeder) and Main F (supplied by the B1 feeder) experiencing a dead source. This now allows Tier 2, ATS 4 to call and switch to the emergency generator source.

B. Hot Standby

Hot-standby function effectively blocks an automatic retransfer operation. It keeps a live source on standby when operating with the tie breaker closed. It is typically useful in performing restoration in a controlled manner.

It is suggested to have the optionality to enable or disable hot-standby function, typically using a pushbutton function in the ATS controller or utilizing other means such as a switch. The hot-standby function can be individually implemented for each main breaker in the ATS.

The hot-standby function is commonly combined with a live-source-seeking function (described later in this section). In such an application, when hot standby is enabled, the ATS does not retransfer to a main breaker when the source is healthy unless the other source is dead and the other main breaker is open. When the source feeding the system is lost in this mode, the ATS performs live-source seeking and transfers to either healthy source if and when one is available.

For example, consider Tier 1, ATS 1, where Main A is feeding both the buses, Tie AB is closed, the Main B source is dead, and hot standby is enabled in the Main B ATS controller. When the Main B source returns and is healthy, the hot-standby mode prevents the ATS controller from retransferring back to the Main B source. However, if the Main A source that is feeding both the buses is lost in this condition, the live-source-seeking logic causes the ATS to switch to Main B after the Main A breaker is opened.

C. Live-Source Seeking

The live-source-seeking function enables the ATS to seek a live source when placed in automatic mode.

For example, consider the transfer scheme between ATS 1 and ATS 4 in Fig. 2 that switches between the utility source and the emergency generator source. During an open-transition retransfer, if the utility breaker fails to close after the generator-side breaker is opened and if the generator source is still healthy, the generator-side breaker closes again as the ATS seeks the live source.

D. Breaker Operation Failure

Breaker operation fail detection identifies when the breaker does not complete its intended operation. This includes both breaker trip failure and breaker close failure. Both can be identified using built-in logic in devices such as modern microprocessor relays or by using custom logic based on breaker trip or close time information available in the breaker data sheet or operation manual.

Once a breaker operation failure is detected, it can be used to block future automatic operations to prevent the occurrence of future automatic breaker misoperations. A common method of implementation is using a latch that is set when a breaker operation failure is detected. This latch is then used to block future automatic operations. After performing maintenance, the latch can be reset (for example, by using a pushbutton on the

ATS controller), thus allowing the automatic operation to be restored.

In addition, breaker operation failure detection can raise alarms, such as breaker trip fail, breaker close fail, and automatic operation fail.

It is recommended that the system be put in manual mode when performing maintenance to prevent accidental breaker operations and misoperations due to a broken sequence of automatic operations. Switching the system from manual to automatic mode after completing maintenance and restoration actions also allows the standard sequence of operations to be reinstated seamlessly.

In addition, breaker trip fail detection during a fault can be used to speed up backup protection. For example, a breaker trip failure at the main breaker of an ATS for a downstream fault can be communicated to the upstream relay to trip the upstream breaker faster instead of having to wait for the slower protection element, such as time-overcurrent, to trip as backup protection.

E. Antiparallel Function

As the name suggests, the antiparalleling function prevents two sources of an ATS from being connected together. The ATS can be programmed to implement the antiparalleling function in automatic mode, manual mode, or both.

Implementing antiparallel logic in the ATS helps mitigate certain risks and offers some benefits. It helps prevent circulating currents when the two upstream transformers feeding the ATS have different impedances or operate at different taps. Additionally, the switchgear may not be rated to withstand the combined short-circuit capacity of the paralleled sources. Antiparalleling logic is also used when different grounding methods on the two sides of the ATS are present, such as one source that is solidly grounded and another that is impedance-grounded. Furthermore, antiparallel logic can be used to prevent backfeeding from one source to another.

Consider a main-tie-main ATS with antiparalleling logic implemented. When all three breakers are closed, resulting in parallelling both main sources, the antiparalleling logic trips the tie breaker. If the tie breaker fails to trip during an automatic retransfer operation, the main breaker that just closed is tripped to prevent paralleling of sources.

Another method of implementing antiparalleling logic is by using a selector switch. The selector switch, commonly referred to as Switch 10, can be used to choose the source that should be tripped when the sources are paralleled. However, care should be taken when programming the antiparallel logic in this case, as tripping a breaker based on the selector switch may not accommodate tripping an alternate breaker when a breaker trip fail occurs while the sources are paralleled. Antiparallel circuits with Switch 10 selector switches are discussed further in Section VII (Step 4) of this paper.

F. Transfer and Retransfer Inhibit Function

This function is another form of inhibiting or blocking a transfer or retransfer operation. When the inhibit function is enabled, it stops the automatic operation (transfer or retransfer) from being executed. Once the inhibit is removed, the automatic operation shall be performed. This function is programmed with the ability to enable or disable as required, such as using a pushbutton on the ATS controller or remote commands using supervisory control and data acquisition (SCADA).

It can be deployed to perform an operation (transfer or retransfer) in a controlled manner. For example, transfer inhibit can be programmed to stop the ATS from transferring to a set of generators until all or a sufficient number of generators connected to the bus are online. Similarly, retransfer inhibit can be used to stop a retransfer operation to ensure the restored source is healthy and stable.

VII. Step 4: ATS Switchgear Design Considerations

Switchgear design and selection of auxiliary devices for an automatic transfer scheme are critical to achieve reliability of the ATS and ensure safe operation during load switching. This section discusses the recommended design practices for ATSs.

A. 43-AM Switch

The intent of providing the automatic-manual switch as a part of a transfer scheme is to distinctly perform the transfer operations in automatic and manual modes. The ATS logic and the physical switchgear should be designed so that when the 43-AM is selected to be in manual mode, no automatic breaker operations should take place to ensure safety of personnel in front of the switchgear. In other words, automatic functions such as automatic transfer and retransfer, live-source seeking, and automatic generator call should not take place unless manually initiated by the operator. On the other hand, placing the 43-AM in automatic mode should allow the ATS operations without intervention by an operator.

A 43-AM switch function is achieved either by installing a two-way physical switch as a part of the ATS switchgear or via software logic in the human-machine interface (HMI) or front-panel pushbutton of a logic controller. Wherever possible, it is recommended to have a physical 43-AM switch instead of a logically programmed 43-AM function, especially when more than one device is involved in the ATS to communicate the status of the 43-AM switch. When contacts of such physical two-way switches are hardwired, a 43-AM should indicate logical 1 when in automatic mode and logical 0 when in manual mode to block the automatic operations during a loss of control power. Additionally, contacts of a physical 43-AM switch could be wired in a breaker close and trip circuit so that a failure of a logic controller, communications channels, maintenance of a device, etc., would still allow the manual transfer and retransfer of the loads.

B. Breaker Close and Trip Circuit

For ATS breakers, the breaker close circuit should have two parallel closing paths with 43-AM switch contact supervision. Both paths are supervised for voltage and fault conditions to close the breaker, as shown by the close permissive (25X) and lockouts (86M1, 86T, and 86B1) in Fig. 8. The manual close of the breaker should have minimal dependency on the health of the communications channels and be independent of the ATS logic programmed in a controller. Typically, the only function and dependency in a manual breaker close operation is a synchronism check to perform closed-transition transfers and retransfers.

In contrast to the breaker close circuit, the trip circuit should be independent of the status of the 43-AM switch and should allow the breaker to trip via a control switch, remotely via HMI, or for an ATS.

C. Switch 10 (Select to Trip)

A select-to-trip switch is used to implement a hardwired antiparallel scheme without the logical and communications dependency on the ATS logic controller during manual switching operations. Please note that a hardwired Switch 10 does not eliminate the need for antiparallel logic in ATS controllers. For automatic operations, it is recommended to program an antiparallel logic in the controller to detect breaker failure conditions during paralleling, which hardwired connections generally do not provide.

Fig. 8 shows a typical main breaker close and trip circuit for a main-tie-main ATS with 43-AM, Switch 10, lockout, and ATS controller contacts wired. The concept of the main breaker circuit can be extended to the tie breaker circuit as well.

D. Potential Transformers (PTs)

The location of PTs is often a point of discussion during the design process of an ATS due to economic factors or space constraint within switchgear, especially for an LV system or motor control centers. Following is a general guideline for providing PTs as a part of ATS switchgear.

- Since almost all MV and LV industrial switchgear units use three-phase breakers for ATS operation, and the automatic transfer initiation requires the detection of loss of source based on three-phase undervoltage, a three-phase PT, either wye- or delta-connected, should be used for the incoming line. Having a three-phase PT also avoids a spurious transfer initiate condition when one of the PT secondary fuses gets blown.
- As discussed in previous sections, to achieve open-transition residual transfer, an alternate breaker source should be closed only after detecting a dead bus condition. For example, in a main-tie-main

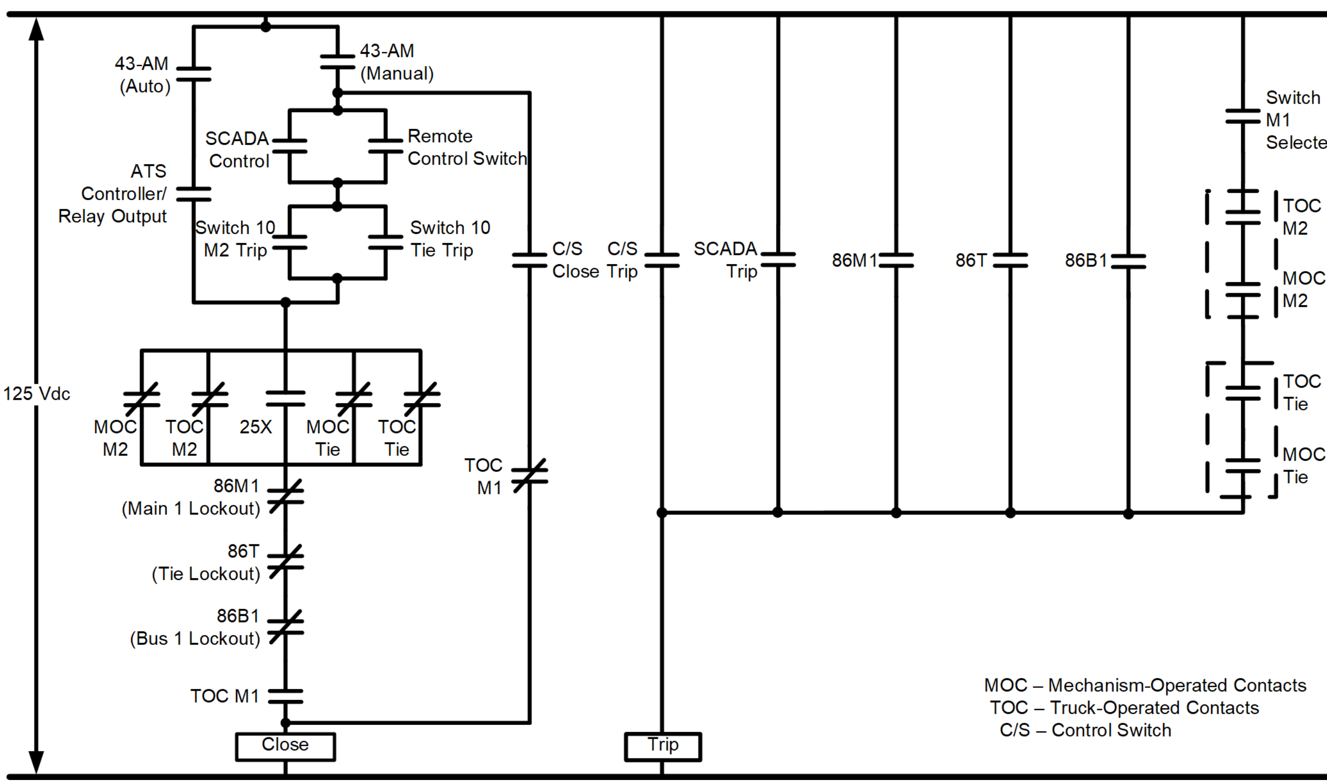

Fig. 8. Typical breaker close and trip circuit for main incomer breaker as a part of main-tie-main switchgear configuration.

configuration, a separate bus PT should be provided to detect the true dead condition. When separate bus PTs are not provided, a custom logic algorithm comprising breaker positions can be used or a hardwired connection can be made to determine the dead bus condition, but care should be taken since deriving the dead bus voltage based on the breaker status and incoming line voltage does not represent the true potential at the bus, and it does not reflect the effect of connected loads on the bus voltage.

One of the major functions for the ATS is to perform synchronization during a closed-transition transfer and retransfers. Consider the use of line-to-line phases from a PT to perform a sync-check. In cases in which two or more redundant controllers or relays are used for ATS logic, wiring different line-to-line phases for a sync-check function increases the reliability of the scheme. For example, Controller 1 can use the line-to-line phase (A-phase-to-B-phase) for a sync-check and Controller 2 can use the line-to-line phase (B-phase-to-C-phase). Reference [16] provides more details regarding the redundancy for switchgear design and sync-check functions.

E. CTs

The location and polarity of a CT determines the transfer initiate and blocking conditions. As explained in Section IV (Step 1), switchgear drawings need to be verified with the transfer initiate and blocking conditions.

Another common question that protection engineers come across is the provision of a separate CT at the tie breaker. With a provision of a separate CT at the tie breaker, selective overcurrent coordination can be provided. This way, a fault on the bus can trip only the respective main breaker and tie breaker and still have the other main breaker feed the loads on the unaffected bus. In case the coordination time interval is not achieved, the same set points are programmed in tie relays as in the main incomer breaker.

For LV schemes, if separate CTs are wired to the ATS logic controller, the breaker's bell alarm contact can be wired from the LV breaker to the ATS controller to indicate the fault conditions, thereby blocking the transfers.

F. Communications for ATS

In an ATS, multiple devices are involved in the exchange of data through communications channels, which is crucial for the execution of programmed functions in the ATS controller. When selecting a communications channel, it is important to consider the following criteria.

- The communications protocol used should be able to detect errors in the communications channel in order to disable the ATS when necessary. It is essential to note that a failure of a communications channel connected to the ATS controller should not result in the blocking of all automatic transfers. For instance, in a communications-assisted scheme, the loss of communications with upstream devices used for transfer initiate conditions for fast and staggered transfers should still permit backup residual automatic transfers while only disabling the fast and staggered automatic transfers.
- In a scheme in which multiple devices are exchanging data for ATS functions via Ethernet switches, it is advisable to establish a separate communications network by assigning a dedicated switch or utilize virtual local-area network (VLAN) or software-defined networking (SDN) technologies to minimize latency for transfer trips.
- Moreover, for ATS operations, the selected communications protocol should provide flexibility to exchange the required number of transfer bits, and the speed of data exchange should be fast enough to achieve transfer operations within the desired time frame.
- The devices involved in ATS operations should also have IRIG connections or Network Time Protocol to provide accurate time stamping for the event recording and validate the transfer time during testing.

G. Control Power for ATS Controller and Inputs/Outputs (I/O)

In many distribution systems, control power for the ATS controllers is supplied via a control power transformer within switchgear. During the loss of primary power, the ATS controller loses the control power. A redundant control power via UPS or a backup dc battery system should be provided to keep the ATS in operation. In the worst-case scenario, even if the control power is momentarily lost, the ATS should remain enabled.

VIII. Step 5: Ensure Protection Considerations and Coordination

This section describes the protection considerations in conjunction with an ATS where applicable.

A. Protection Coordination Considerations

The main incomer breakers for certain ATS configurations are combined with a fast bus tripping scheme to provide bus protection. For such schemes, when the ATS operates to transfer the load from one source to the other, a combined inrush current from the feeder transformers or connected motor loads can cause the fast bus tripping scheme to operate spuriously if the pickup for the fast bus tripping scheme in the main incomer is not set above this combined inrush current level. Comprehensive coordination checks for the overcurrent pickup for fast bus tripping schemes are recommended. There might be cases where the available fault current from the source for a fast bus trip is not large enough and the set point for fast bus tripping cannot be programmed above the combined inrush current. One of the solutions to this is to send a blocking signal to block the fast bus trip protection function for a few seconds after a successful breaker close during ATS operation. Fig. 9 shows a simplified one-line diagram and inrush current coordination check for a fast bus tripping scheme.

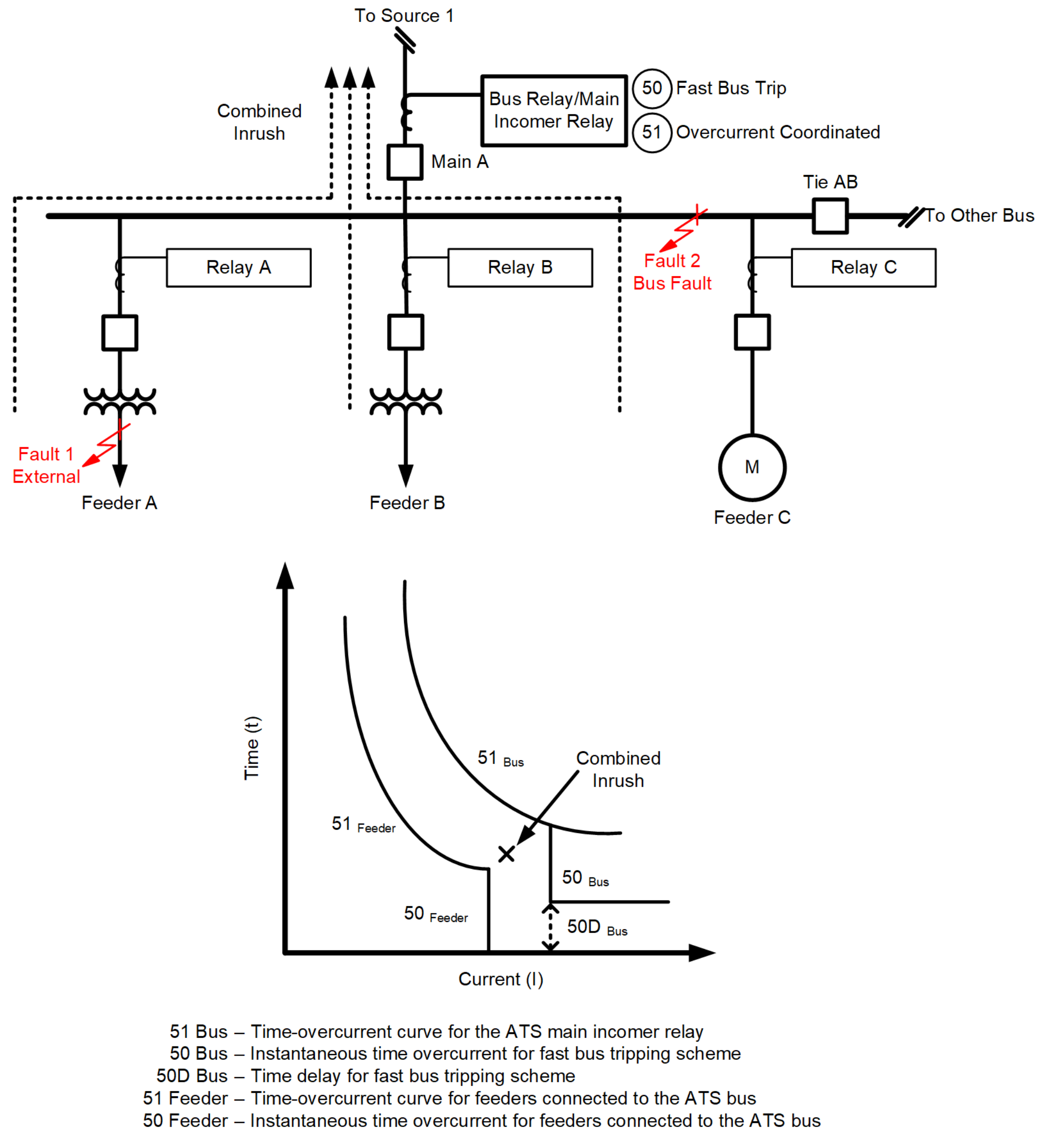

Fig. 9. Typical breaker close and trip circuit for main incomer breaker as a part of main-tie-main switchgear configuration.

Similarly, in cases in which more than one automatic transfer scheme operates simultaneously, the combined inrush current resulting from all the parallel ATS operations can cause the backup overcurrent of the main transformer protection to operate falsely. The set point for the backup overcurrent element should be set above the combined inrush current level or have the parallel ATS operate in a staggered manner with a time delay as discussed in Section IV (Step 1). In Fig. 2, Transformer 2 will detect a large inrush current when ATS 1 and ATS 2 operate simultaneously upon loss of Utility Source 1.

Apart from the overcurrent coordination, undervoltage conditions for specific loads must be coordinated with the ATS's transfer time. For example, for the residual transfer scheme, motor load relays without autorestart logic and certain capacitor bank relays are programmed with an undervoltage element that trips the respective load breakers after a few seconds of time delay upon the loss of primary source voltage. Tripping such loads allows operators to start the motors and connect capacitor banks sequentially in a controlled manner. The undervoltage time delay for such loads should be set lower than the ATS time required to transfer the loads from one source to the other.

On the other hand, if the intention of having a feeder relay undervoltage element is to keep the loads connected during a transfer, the time delay selected for such relays should be greater than the time required for ATS to complete the transfer.

In both cases, the undervoltage element checks are warranted in all feeder relays in conjunction with ATS transfer time.

In situations in which the residual voltage transfer is prolonged due to large motors causing slower voltage decay, a different technique known as a "transfer shield" can be utilized. For example, in a communications-assisted fast transfer, a transfer shield signal can be sent from the main incomer relays to the motor relays when the fast transfer is initiated. Upon receiving this transfer shield signal, the motor relays trip open the motor breaker.

B. Loss-of-Potential (LOP) Logic

An LOP condition is used to detect blown PT fuses. In ATS logic, the LOP condition is used to block the automatic transfer and to stop the loads from transferring to the other source when blown fuses are detected. While LOP logic works for most cases in ATS logic, it should be used with caution. In certain cases, as described later in this subsection, for a true loss-of-source event in which the ATS is expected to transfer the load to the other source, a false assertion of the LOP results in preventing the loads from transferring.

For example, for a low-load condition when the bus is operating with less than 10 percent of nominal current, LOP supervision in a transfer initiate condition would falsely block the transfer.

For motor loads, in the event of loss of source, the current would decay in almost 6 to 8 cycles, whereas the bus voltage might remain high for a longer period, which might cause an LOP to pick up and block the transfer initiate.

For such cases, consider removing LOP supervision from any transfer initiation logic to allow for a transfer to proceed as intended. Instead, it is recommended to supervise a transfer initiate condition by using a three-phase undervoltage (3P27) condition and keeping an LOP as an alarm only. This prevents any transfer for one or two blown fuses and helps prevent a false LOP from affecting the transfer scheme.

As an alternative, instead of using LOP supervision directly in the transfer initiate condition, a latch with a minimum current supervision can also be added in a transfer initiate condition.

C. High-Resistance Grounding (HRG) for LV Systems

HRG is widely used for LV 480/208 V switchgear. The purpose of an HRG system on each bus is to allow the bus to remain in operation even when there is a single-phase-to-ground fault somewhere among the loads. For ATS applications, HRG fault alarms are wired from the HRG units to the ATS logic controller, as shown in Fig. 10. Following are some of the protection and logic considerations to evaluate when an ATS is combined with HRG units.

An ATS is allowed to perform transfer operations when the HRG units detect ground faults from the transformer wye-winding neutral. However, a tie breaker should be blocked from closing in both automatic and manual modes if there is a ground fault on both buses, as it could create a phase-to-phase-to-ground fault by closing the tie breaker. For example, one side of the bus has an AG fault, whereas the other bus has a BG fault. Closing the tie breaker creates an ABG fault.

In LV transfer schemes, wye-connected PTs might be used to allow the main relays to monitor harmonics. During an HRG fault, the grounded phase shows zero potential, which could cause an unwanted automatic transfer. This can be avoided by using only phase-to-phase undervoltage or all three-phase undervoltage elements for initiating automatic transfer.

It is recommended that a latch be programmed in the ATS logic when an HRG alarm asserts as the ground fault indication signal can be reset after the main breaker has been opened. As a result, the HRG unit no longer detects the fault on the bus.

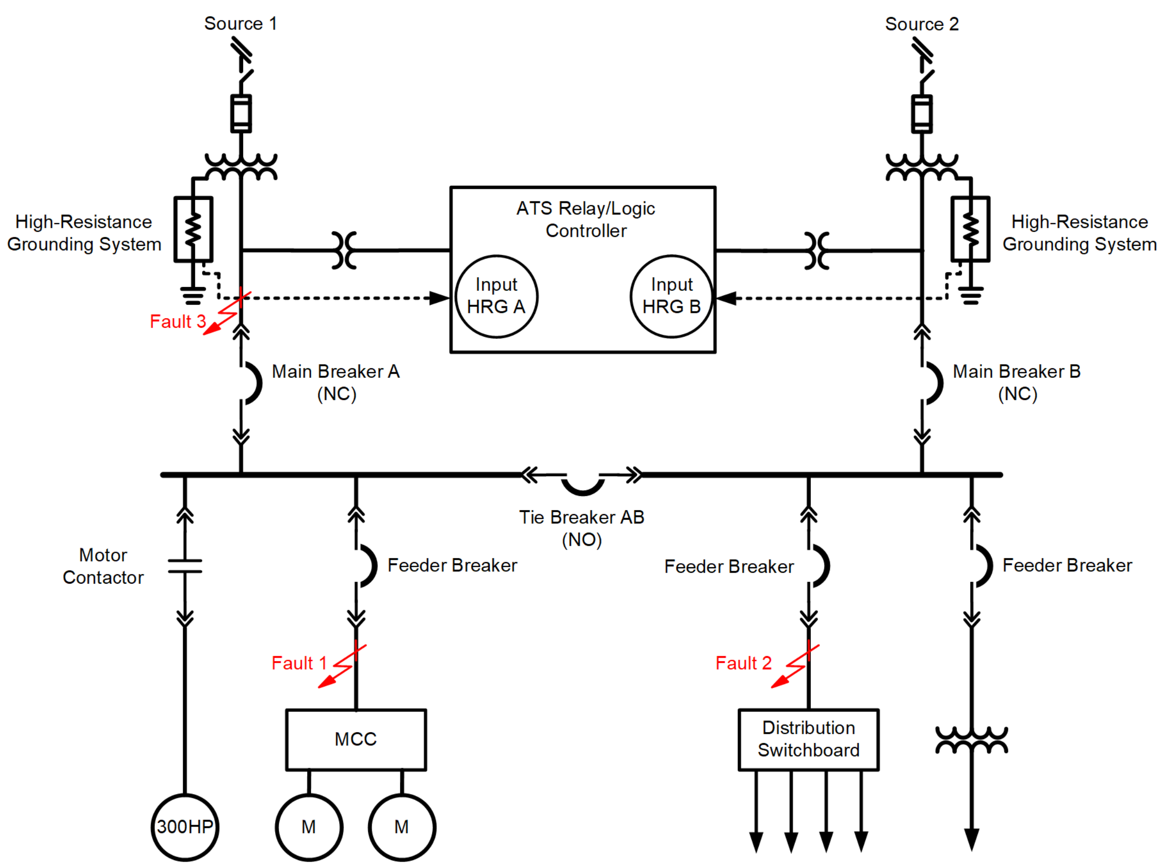

Fig. 10. ATS application for switchgear with HRG.

The latch maintains the knowledge of a ground fault on Bus A after the main breaker is opened, so that if there is a ground fault on Bus B, the tie is still blocked from closing into a potential phase-to-phase-to-ground fault. If there was a ground fault on Bus A before a transfer, this latch remains high, which prevents the other relay's HRG latch from being set when the Bus B HRG unit detects the ground fault on Bus A. Thus, it is still only indicating one ground fault and also indicates which bus the ground fault is on. If a ground fault develops after the buses are tied together, then the connected HRG unit could set the latch in the relay for the incorrect bus, but this is easily identified once the tie has been opened for the open-transition retransfer.

At all times, the main breaker is blocked from closing if the HRG unit detects an active ground fault because that would indicate that the fault is between the transformer and the breaker, which is an unlikely location and should be easily resolved before closing the main breaker since the alternative could close a known ground fault onto an undetected bus ground fault.

D. Protection Lockouts (86) for ATS

When creating ATS logic, protection engineers sometimes make the mistake of programming the outputs for the main incomer breaker lockout, such as 86M1 or 86M2, for all protection trips, without considering the protection functions and CT placement that should not trigger the lockout. This oversight can unintentionally block the ATS, causing loads to fail to transfer. For example, the CT for the main incomer breaker can serve the dual purpose of facilitating incomer cable differential protection or directional overcurrent and providing backup overcurrent protection for downstream feeders. In this scenario, the downstream overcurrent protection should be designed to block the transfer and activate the lockout, while the differential protection and directional overcurrent should be configured to initiate the transfer.

IX. Step 6: Testing and Commissioning of ATS

As a crucial final step, it is essential to thoroughly validate the design and programming of an ATS through extensive testing during both the factory acceptance test (FAT) and site acceptance test (SAT) before the scheme is energized. This is especially important for systems involving multiple upstream and downstream devices.

Besides conducting ATS controller I/O checks and metering checks for CTs and PTs, as well as testing protection elements, it is important to perform a variety of scenarios to ensure the proper functionality of the ATS. These scenarios include both positive conditions that enable the scheme and negative conditions that should block scheme operations as intended. Please note that this list of scenarios to test is not exhaustive and may vary depending on the specific transfer scheme.

- Manual transfer operation scenarios

  This may involve checking manual transfers locally from the switchgear and remotely via SCADA or HMI for all breakers under various voltage and fault conditions. Maintaining a log of standard operating procedures for a manual transfer is advantageous for the plant operation team conducting routine maintenance.

- Automatic operations

  Automatic transfer operations should be checked for different initiate conditions. These automatic scenarios also include the verification of additional functions such as auto-retransfer, generator call, and hot standby.

- Negative conditions to test:
  - Instances of reduced voltage or out-of-sync conditions that should block manual and automatic transfers.
  - Conditions that block automatic operations.
  - Scenarios involving breaker trip and close failure, along with strategies to restore the system to normal after such breaker failure conditions.
  - Communications failure conditions for both manual and automatic operations.
  - Loss and restoration of control power to the ATS controller to prevent changes in the ATS breakers' states.

While performing these scenarios, it is essential to pay attention to the following points.

- Keep a detailed record of Sequential Events Recorder (SER) to validate the precise sequence of operations and the time needed to execute transfers. Fig. 11 shows an example of an SER recorded during a transfer. Bit 35 is a transfer initiate signal received from an upstream device and sent to the ATS controller. Once the ATS controller detects a three-phase undervoltage (Bit 26), it initiates the transfer and opens the main incomer breaker shown by Bit 18 and closes Tie Breaker 14. All the bits in this example are not explained to maintain the brevity of the paper.

#	DATE	TIME	ELEMENT	STATE	Annotation
39	2019/06/27	15:59:03.440	RMB4A	Asserted	
38	2019/06/27	15:59:13.431	SV32T	Asserted	
37	2019/06/27	15:59:13.435	SV31T	Asserted	
36	2019/06/27	15:59:13.439	SV03T	Asserted	
35	2019/06/27	15:59:28.269	RMB2B	Asserted	Transfer initiate bit received from upstream
34	2019/06/27	15:59:28.273	3P59	Deasserted	
33	2019/06/27	15:59:28.273	OUT403	Deasserted	
32	2019/06/27	15:59:28.273	SV06T	Deasserted	
31	2019/06/27	15:59:28.273	SV03T	Deasserted	
30	2019/06/27	15:59:28.273	25A1	Deasserted	
29	2019/06/27	15:59:28.273	27PP2	Asserted	
28	2019/06/27	15:59:28.277	59PP1T	Deasserted	
27	2019/06/27	15:59:28.286	27PP1T	Asserted	
26	2019/06/27	15:59:28.290	3P27	Asserted	Three-phase undervoltage detected at main incomer
25	2019/06/27	15:59:28.290	SV08T	Asserted	
24	2019/06/27	15:59:28.294	SV07T	Asserted	
23	2019/06/27	15:59:28.294	SV05T	Asserted	
22	2019/06/27	15:59:28.311	OUT302	Asserted	
21	2019/06/27	15:59:28.311	OUT102	Asserted	
20	2019/06/27	15:59:28.311	SV18T	Asserted	
19	2019/06/27	15:59:28.311	SV27T	Asserted	
18	2019/06/27	15:59:28.365	52A	Deasserted	Main incomer breaker opened for open-transition transfer
17	2019/06/27	15:59:28.365	IN301	Deasserted	
16	2019/06/27	15:59:28.365	OUT303	Asserted	
15	2019/06/27	15:59:28.365	SV12T	Asserted	
14	2019/06/27	15:59:28.386	IN302	Asserted	Tie breaker closed to complete the transfer
13	2019/06/27	15:59:28.386	OUT402	Deasserted	
12	2019/06/27	15:59:28.386	SV08T	Deasserted	

Fig. 11. Example SER from automatic transfer event.

- Ensure the event record for the transfer event is long enough to capture the complete event from the transfer initiation to the completion of the transfer. The event report is a useful tool to validate the transfer time programmed in the ATS controller, analyze the effect of different loads, verify communications bits exchanged during transfer, and help optimize the transfer time.
- Perform end-to-end testing using synchronized clocks where multiple devices are physically located at different places and transfer permissive and blocking conditions are exchanged from one device to the other, specifically for communications-assisted schemes, to verify the functionality and reliability of integrated communications systems. For example, transfer initiate signals might be exchanged via differential communications channels from an upstream device to the downstream main incomer ATS controller. This kind of comprehensive testing can help eliminate a logical racing condition that might not be captured when the standalone ATS system is tested.
- Highlight the logic drawings to ensure that all logical operations are thoroughly tested and documented.
- Utilize secondary injection, employing the actual event file, to thoroughly evaluate the response of the scheme under various simulated scenarios. This helps to ensure that the scheme performs as intended in a real-world event. For example, a COMTRADE file can be obtained from the past event or from the study, which can be replayed back using a secondary injection test set.

X. Conclusion

This paper aims to provide detailed guidance and raise awareness about the various topologies commonly used for ATSs in industrial facilities, especially in situations in which multiple schemes coexist within a single facility.

The following are key takeaways from the paper for developing an ATS.

- Define the objective of the scheme within the overall system and how it will be used in the system operation. Involve all the stakeholders from the initial stage to develop a robust scheme, including P&C design engineers, protection engineers, automation engineers, and plant owners or operators.
- Determine the conditions for initiating an automatic transfer and consider the potential for false positive initiation. Also, take into account the impact of loads that are directly connected to the ATS bus.
- Calculate transfer timings and ensure they meet the transfer time or ride-through requirements of the loads. Consider the use of communications-assisted transfer schemes to reduce transfer initiation delays and execute automatic transfers faster in certain applications. Coordinate transfer times by introducing a stagger transfer if other parallel, upstream, or downstream ATSs exist within the same power system.
- Ensure the auxiliary devices, ATS controller, and communications method used meet the requirements for the ATS. In addition, a switchgear design should be considered in conjunction with the desired functions, ease of operation, and ability to provide redundancy.
- Carefully consider the protection functions to be implemented in conjunction with the ATS. Clearly defining the protection zones is paramount to the proper operation of the ATS and its functions.
- Determine the functions to be implemented in the initial stages of developing the ATS. Ensure the functions operate harmoniously with each other without any unpredictable operation.
- Create a functional design specification document to document all the aforementioned details for ease of development of the ATS, execution, and future guidance for plant operation.
- After the scheme has been developed, test the scheme comprehensively to verify the operation, system protection, functions, communications between devices, transfer trips, and signal exchanges among different devices. Keep detailed records of the testing performed. It is suggested to perform an FAT and/or SAT to achieve this.

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XII. Biographies

Rikesh Shah received his BSEE from Maharaja Sayajirao University (MSU) in 2013 and MSEE from University of Houston in 2017. He worked as a substation design engineer at Tebian Electric Apparatus for two years. In 2017, he joined Schweitzer Engineering Laboratories, Inc., (SEL) in the SEL Engineering Services, Inc., division. He presently serves as a project engineer in protection for SEL in Houston, Texas. Rikesh is a registered professional engineer in the state of Texas.

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Pratik Patel received his BE in electrical engineering from Gujarat University, India, in 2006 and an MSEE from Northwestern Polytechnic University, CA, in 2010. Pratik joined Schweitzer Engineering Laboratories, Inc., (SEL) in 2014. He has served many electric utilities and customers throughout the U.S. by providing protection and control design packages to protect transmission, distribution, and generation equipment. Pratik is an IEEE member.

William Shane Reed received his BSEE from The University of Texas at Austin in 2004. He works at Samsung Austin Semiconductor as a principal engineer and is a registered professional engineer in the state of Texas.

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