

# Using GOOSE Messages in a Main-Tie-Main Scheme

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**Abstract --** Main-tie-main (MTM) transfer schemes increase reliability in a power system by switching a load bus to a secondary power source when a power interruption occurs on the primary source. Traditionally, the large number of physical I/O lines required makes main-tie-main schemes expensive to design and implement. Using Ethernet-based IEC 61850, these hardwired I/O lines can be removed and replaced with generic object-oriented substation event (GOOSE) messages. Adjusting the scheme for optimal performance is done via software which saves redesign time and rewiring time.

Special attention is paid to change-of-state GOOSE only; no analog GOOSE messages are used, making the scheme fast and easy to configure, maintain, and troubleshoot. Applications such as fast motor-bus transfer are discussed with synchronization remaining at each breaker relay. Simulation test results recorded GOOSE message latencies on a system configured for a main-tie-main scheme. This paper presents details of open and closed, manual and automatic transfers.

**Index Terms--**IEC 61850, digital GOOSE messages, main-tie-main scheme, reliability, troubleshooting, fast motor bus transfer.

## I. INTRODUCTION

Main-tie-main (MTM) transfer schemes increase reliability in a power system because there are two sources that can power buses via a tie circuit breaker, thus minimizing outages. The IEC 61850 MTM scheme is more secure than conventional methods because traditional copper-wire connection(s) can fail with no notice. IEC 61850 MTM schemes send immediate alerts because of the loss of GOOSE system health messages [2, 3].

The IEC 61850 main-tie-main scheme is implemented in software using a substation Ethernet LAN. Thus the engineering design time, drawing time, number of auxiliary devices and amount of wiring is reduced which lowers the initial installation cost. See Fig. 1.

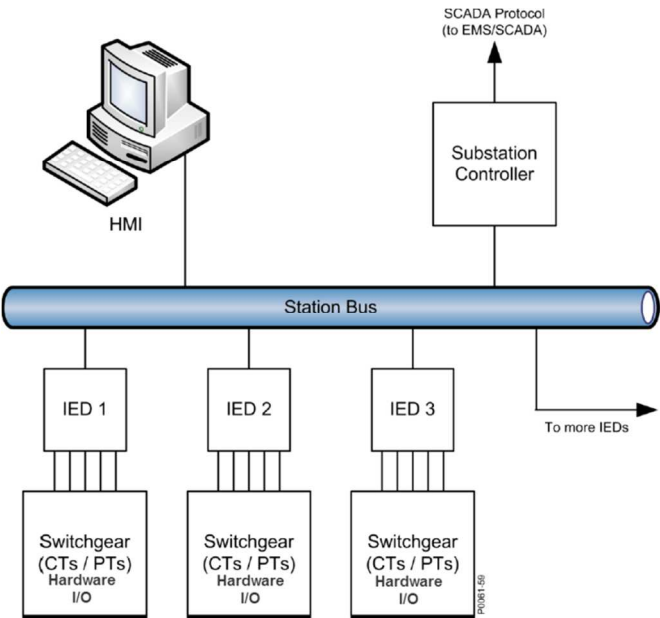


Fig. 1. Basic LAN for IEC 61850 Communication

Typically, these schemes consist of two main power sources (utility/utility or utility/local generation) each feeding two main buses. The two buses can be tied together and fed from just one of the main power sources if the other source fails. There are three circuit breakers; one for Main 1, one for Main 2, and one for the bus tie. Traditionally, one protective relay is associated with each of these circuit breakers and is known as a three-relay, main-tie-main scheme. See Fig. 2.

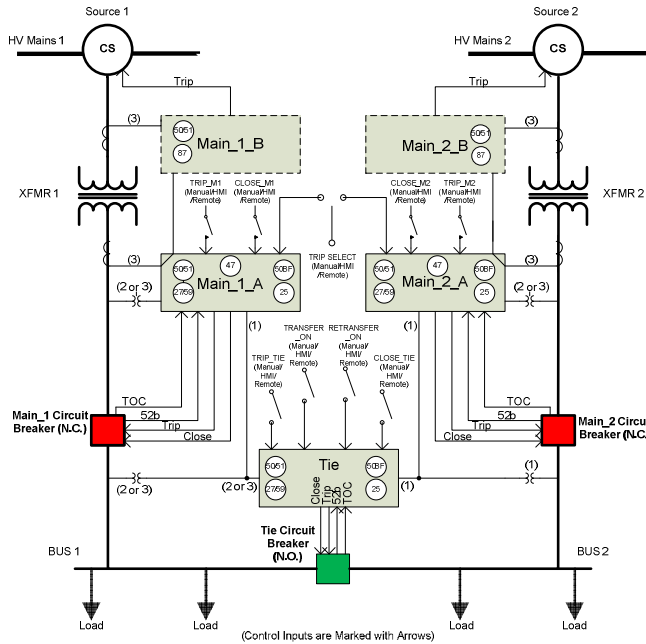


Fig. 2. Three-Relay Main-Tie-Main Scheme

The scheme of Fig. 2 is for a MTM scheme where the three relays have analog inputs from both sides of the connected buses via PTs. Although possible, this paper does not discuss moving the analog values via GOOSE messages. Element change-of-state GOOSE is simpler to implement, easier to customize and modify, and yields faster troubleshooting in the field. Two-relay MTM schemes are possible but are more difficult to implement using only change-of-state GOOSE messaging.

The relays contain all scheme logic and documentation. Therefore, testing and commissioning is straightforward, with reports that document scheme operation, and allows easy misoperation troubleshooting. The result is reduced operating and maintenance costs.

## II. MAIN-TIE-MAIN WITH IEC 61850

### A. Timing and Circuit Breaker Closing

A main-tie-main scheme requires fast communication from and to each of the relays and control switches. Fig. 1 shows the substation LAN bus for the IEC 61850 peer-to-peer protocol. These LANs can be made very reliable with configurations such as dual-ring, self-healing arrangements, as well as other new ring multicast technologies. This paper assumes you are familiar with the software that publishes and subscribes to datasets, and creating and reading the required IEC 61850 files. Typical GOOSE message times are in the order of 4 ms [4], and end-to-end command-response times are sufficiently fast to support fast motor bus transfer provided fast synchronizer (25) elements are in each relay.

### Typical 1/4 Cycle Operations Sequence

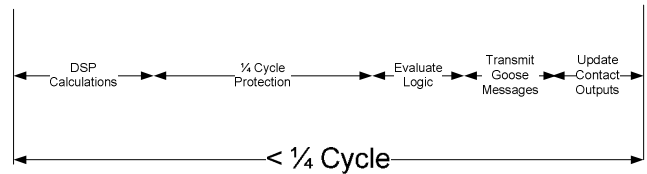


Fig. 3. Internal Relay Operations

### Remote Contact I/O TRIP (Worst Case for a Typical Configuration)

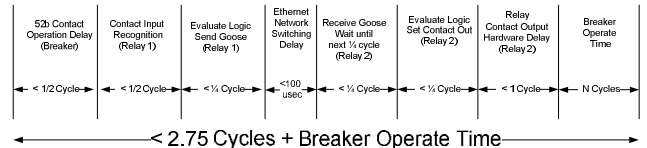


Fig. 4. Contact Input Relay-to-Relay Time

### Remote 50/PIOC TRIP (Worst Case for a Typical Configuration)

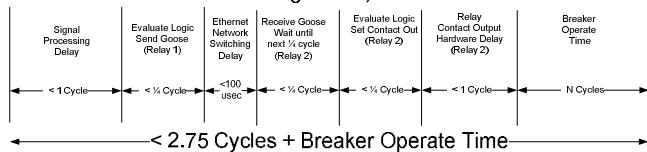


Fig. 5. Element Relay-to-Relay Time

GOOSE messaging with optimized Ethernet hardware (IEC 61850-3 rated) quickly gets information from a Relay 1 change of state to the physical output contact of Relay 2. See the theoretical calculations in Fig. 3, Fig. 4 and Fig 5. Time intervals can be faster or slower depending upon relay internal processing and other variables. The engineer should evaluate and test their scheme before implementation.

Laboratory testing of a typical IEC 61850 GOOSE configuration shows that the average end-to-end transfer time is less than two cycles at 60 Hz (34 ms). This time leaves a large window for attempting a fast motor bus transfer if the closing time of the circuit breaker is fast.

### B. Fast Motor Bus Transfer

For a power system bus with motor loads, a quick restoration of voltage must occur to keep the motor shaft torque shift at a minimum [5]. The connection of a motor back to the system bus after the fast motor bus transfer transition time has expired can damage the motor shaft and can cause nuisance tripping of circuit breakers by closing out of synchronization.

Once voltage is removed from the motor bus, voltage decay occurs rapidly. Reconnecting quickly via IEC 61850 GOOSE messages reduces torque effects on the shaft. According to NEMA/ANSI Standard C50.41-2000 for Fast Motor Bus Transfer System [6], an analytical study of transient torques in the system is recommended. This work

specifies 1.33 per unit V/HZ as a conservative limit. Fig. 6 shows a typical multi-motor bus fast transfer. Be sure undervoltage relays and cts can track the decaying frequency accurately.

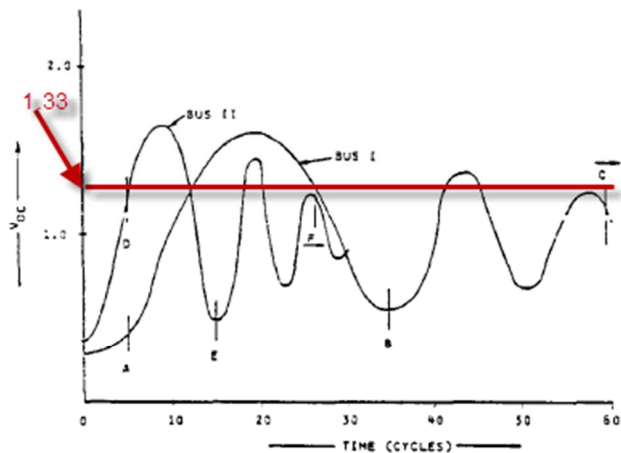


Fig. 6. Fast Multiple Motor Bus Transfer

The tested worst-case IEC 61850 time of three cycles is 50 ms (at 60 Hz), which is a very fast end-to-end time; plus the circuit breaker closing time. If doing a fast motor bus transfer, then the tie circuit breaker close time should be approximately 6 cycles at 60 Hz (100 ms) to allow fast synchronization and margin. Many installed circuit breakers can meet this time specification. Retrofit coils can be added to existing breakers or the tie circuit breaker can be changed for a faster closing unit. Attention must be paid to minimum trip/close time intervals in medium-voltage breakers (IEEE C37.04-1999) [7].

Fig. 7 shows that the fast motor bus transfer period is usually 170 ms depending on the motors, loads, and other power system factors [8, 9].

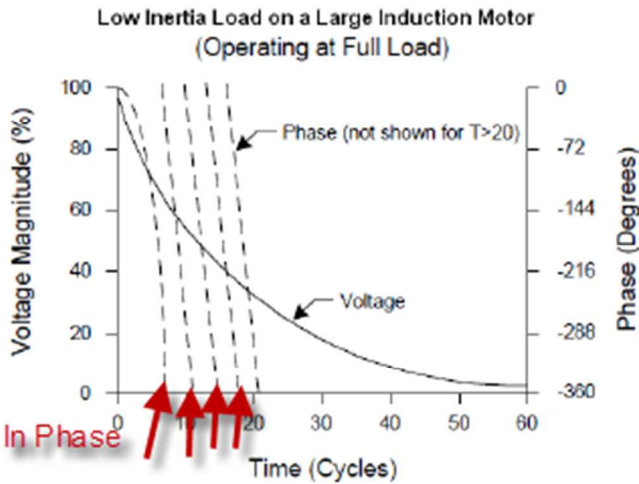


Fig. 7. Motor Bus Transfer Times

If the fast motor bus transfer time cannot be met, an “in-phase” close can be attempted. This close is generated by the IEC 61850 GOOSE messages from the active main and bus relays. See Fig. 7. Fast, anticipatory synchronization is required, which includes the tie circuit breaker relay receiving the permissive GOOSE message, monitoring the decaying motor bus frequency, the phase angle difference, the slip frequency and the delta slip frequency between the motor bus and the new source, and issuing the close at the appropriate time. Usually, load is shed which can be communicated by IEC 61850 GOOSE messages. Careful simulation of this method is required before implementation.

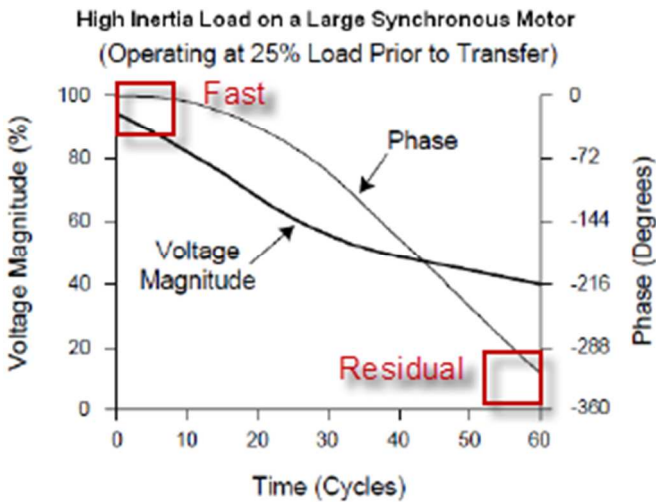
More often, if the fast motor bus transfer time cannot be met, then design engineers will let the voltage at the terminals of motors and other inductive loads return to near zero (residual transfer). Timing for motor bus applications is critical; a detailed analysis of plant processes for a voltage transfer is required. Relay logic timers can supervise a “go/no go” decision in this case, again communicated via IEC 61850 GOOSE messages.

### C. Integrated Machine Control

IEC 61850 GOOSE messages to a generator governor controls could match the generator and line for a faster retransfer. Closed transition retransfer switches with fast operating times can still place a heavy load step on the generator, resulting in frequency and voltage dips and long recovery times. Interconnected remedial action schemes using priority tables [2, 3] and GOOSE messaging can add loads back sequentially to lessen the impact of switching. This is a topic for further investigation.

### D. IEC 61850 Design Process

The design process for an IEC 61850 project, as shown in Fig. 8, starts with collecting the IED Compatibility Description (.ICD) files for each of the relays (using a configuration program) and apparatus to be included in the



substation, together with the system one-line defining the interconnections of the apparatus. These files are combined into a System Specification Description file (.SSD file). The engineer modifies this file by defining the logic, datasets, and GOOSE message requirements to generate operating substation logic and data flow. This new file is a Substation Configuration Description (.SCD file) [10].

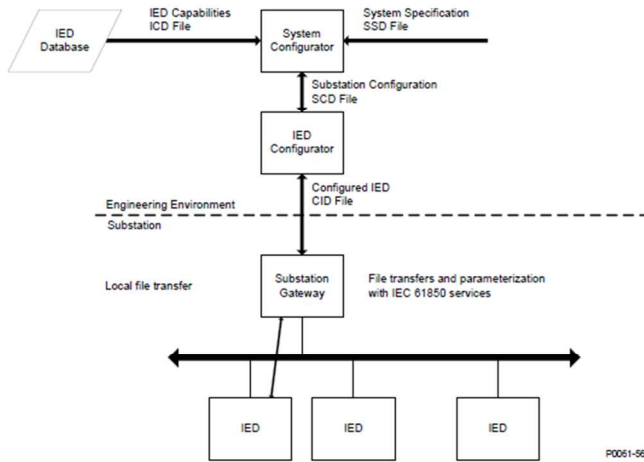


Fig. 8. Information Flow in IEC 61850 Configuration

An IED Configurator sends the .CID file for distribution to the substation gateway for delivery to the separate IEDs (relays). In addition, you can use the configuration software connected directly to the IED to implement the .ICD file. See the IEC 61850 standard and appropriate software manuals for complete information on these methods [1].

#### E. Main-Tie-Main GOOSE Message Examples

Some examples of relay elements that change state and are transmitted by GOOSE messages for main-tie-main schemes follow. The relays are always updated on the health (alarm or watchdog change) of the other relays in the scheme. See Fig. 9 bottom for the Health Bit generator.

Undervoltage (27) elements on the power system mains determine if the voltage of the source is below the acceptable source voltage so the GOOSE messages can command a main circuit breaker to open and allow or initiate the transfer to the tie circuit breaker. Upon transferring, some tie circuit breaker relays can use a simple timing scheme and a dead-line load test controls the retransfer. Other schemes incorporate a sync-check (25) element that monitors both sources and initiates a “soft” retransfer coordinated via GOOSE messaging carrying the result of the synchronizer (25) decision, achieving proper closing.

Current elements (50/51) and transformer differential elements (87) can stop the process if these elements detect bus or other system faults. If a circuit breaker fails to operate a breaker failure (50BF) signal goes to all of the relays in the scheme to stop operation. Unbalance (47) elements detect

excessive negative-sequence currents in the system (for example, stuck circuit breaker poles), thereby declaring a power-system fault and stopping the transfer.

Voltage elements (59) help determine if a main source is stable and ready for retransfer

Not only relay protective elements status are communicated via GOOSE messages, the relays send control and operational status. A remote HMI, relay HMI switches, and actual panel-mounted switches can act as inputs to the relays to generate scheme-control GOOSE messages such as Transfer On, Retransfer On, and preferred source (Trip Select), not to mention close and trip signals for all of the circuit breakers. In turn, the relays generate GOOSE status messages from each circuit breaker to indicate that the breakers are “racked in” (TOC: truck-operated contacts) and the open/closed state of each circuit breaker. Typical GOOSE messages are shown in Fig. 9.

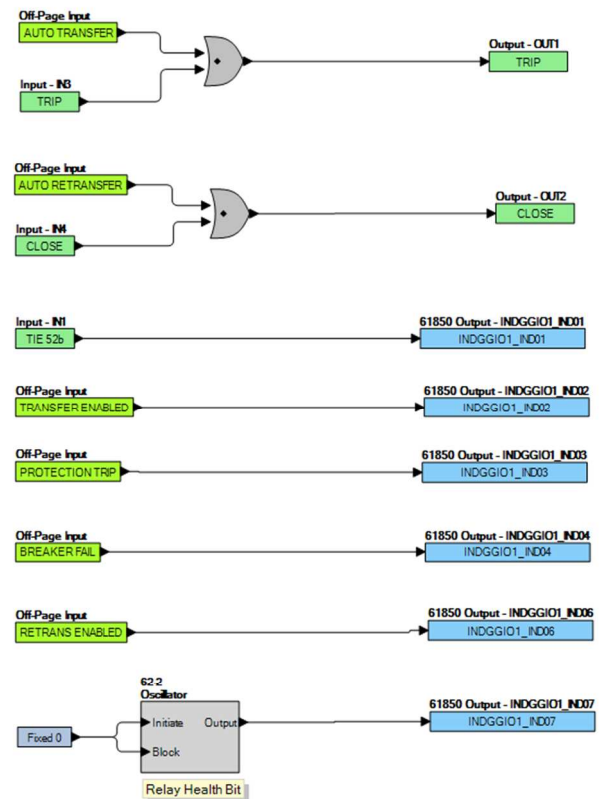


Fig. 9. Typical GOOSE Messages for Inter-Relay Communication

### III. MAIN-TIE-MAIN SCHEMES

MTM schemes can provide closed and open transfers and retransfers. For example, a closed-transition transfer parallels the source, such as a generator with the utility source when a utility outage is predicted, and possibly during a retransfer. Closed transitions prevent torque damage to motor loads and nuisance tripping of breakers. Employing a closed-transition transfer, the system closes the tie circuit breaker and keeps



the main circuit breaker closed for a set time. The engineer should be careful to consider the impact of overdutying equipment during a closed transition.

Closed-transition transfers associated with a utility source require utility approval prior to installation. Utilities will specify protective relay functions, including ground fault protection, to protect the utility power system and avoid islanding. The task of designing and commissioning these protection systems is the MTM scheme engineer's. Connecting to a utility requires on-site inspection and testing in most cases.

The main-tie-main scheme can be a combination of many operational modes. System engineering personnel must select the correct operational mode based upon their particular operating scenarios (utility distribution, industrial processes, hospital backup power, etc). These modes include the following:

- Manual circuit breaker operation
- Manual tie circuit breaker transfer
  - Open transition
  - Closed, synchronized
- Manual retransfer (to main circuit breaker)
  - Open transition
  - Closed, synchronized
- Automatic transfer
- Automatic retransfer
  - Open transition
  - Closed, synchronized

In addition, a well-designed MTM scheme must (in most cases) prevent the closing of all three circuit breakers at once (often called “source paralleling”). With IEC 61850 GOOSE messages and internal relay logic, the outputs of the relay switching decisions and timers can prevent this “backfeed” situation from occurring.

A. Manual Circuit Breaker Operation

Manual transfer can be used for planned transfers during shutdown, startup and certain types of maintenance activities.

Manual operations are from the momentary switch actions for trip and close switches connected to each relay input, and also from remote HMI commands. GOOSE messages supervise the MTM scheme to avoid equipment damage and protect personnel by monitoring the MTM scheme while manual operation occurs.

Remote circuit breaker close and opening, as well as selecting the preferred source (Trip Select), is available using GOOSE messaging via switch inputs through the relays. Sample logic for this activity is shown in Fig. 10 via the relay inputs. Note that an important supervising element is the circuit breaker position via the truck operated contacts (TOC) that indicate the circuit breaker is in place and ready for operation.

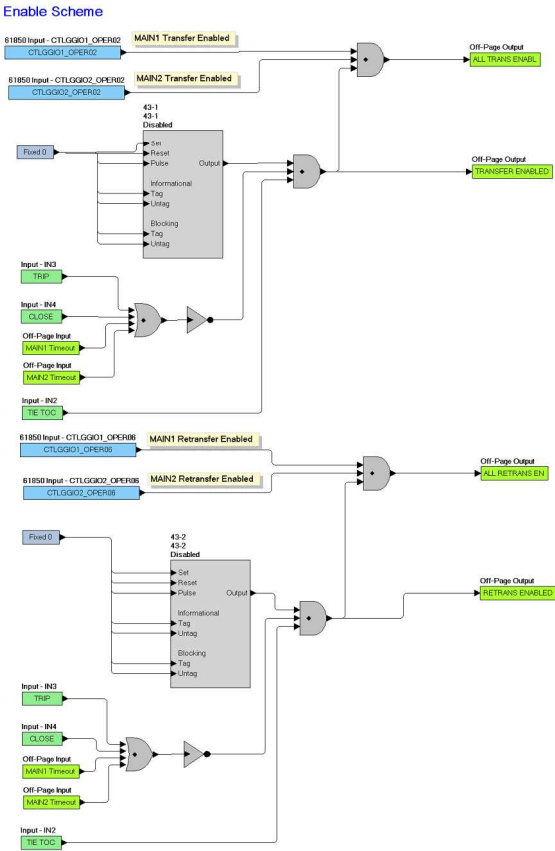


Fig. 10. IEC 61850 Sample Relay Logic for Manual Operation

1) Manual Tie Circuit Breaker Transfer:

You can transfer load manually through the tie circuit breaker to power both buses from the good main source. As previously discussed, the transfer can be closed or open transition. Logic in the relays is always checking for abnormal system operation (power system faults or lack of IEC 61850 health messages).

a) Closed-transition manual transfer:

For a closed transition, this condition can occur only after you have selected one of the main circuit breakers (1 or 2) for tripping via the Trip Select switch. Relay logic makes this choice a toggle or flip/flop selection. Only one main circuit breaker can be chosen to trip when manually closing the tie circuit breaker. Choosing one of the main circuit breakers (1 or 2) for tripping means the relays must have logic not to trip the other main circuit breaker or two circuit breakers might open at once causing a blackout.

For a closed transition, relay logic checks for bus synchronism or for a dead bus. If allowed, the operator closes the tie circuit breaker and the tie circuit breaker relays then send a GOOSE message to the selected tripping main circuit breaker (1 or 2) to trip in the allowed paralleling time. This operation time is limited because strict timings exist for closed-transition switching. See Fig. 11.

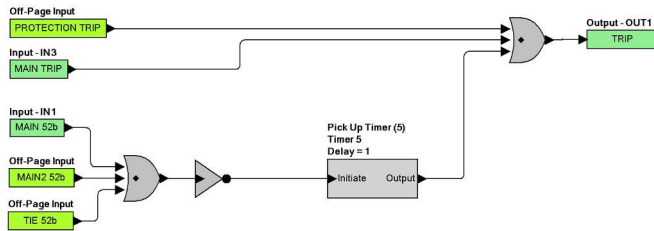


Fig. 11 Timers (62) Determine Closed-Transition Time

### b) Open-transition manual transfer:

For an open manual transition, the operator would open one of the main circuit breakers (1 or 2) causing an immediate GOOSE message from the associated relay that the bus on the opened main source has no voltage, which could supervise the operator to then close the tie circuit breaker manually.

### 2) Manual Retransfer (To Main Circuit Breaker):

As in the transfer, a manual retransfer must occur only if IEC 61850 communication health messages are satisfactory and no faults exist on the power system.

#### a) Closed-transition manual retransfer:

The manual retransfer begins by closing the open main circuit breaker which can occur only when the main source (1 or 2) relay detects that voltage is live, in the good range (27 and 59 elements), there is no 87 differential trip from the main source transformer and there are no other faults. Relay logic and GOOSE messages confirm this situation.

The operator closes the main circuit breaker (1 or 2) and the associated relay broadcasts a GOOSE message to close the tie circuit breaker (if the tie circuit breaker remains open because of operator error or a power-system fault, a GOOSE message is sent to block the retransfer). After the closed-transition timer stops, a permissive GOOSE message goes to main circuit breaker relay. The main circuit breaker relay performs a sync check or dead-bus check and closes. The main circuit breaker relay sends a GOOSE message to allow opening the tie circuit breaker.

#### b) Open-transition manual retransfer:

The previously non-functioning main source relay must detect that source voltage is live (and that there is no 87 differential trip from the main source transformer) so that the main circuit breaker can close. Relay logic and GOOSE messages confirm this situation. The operator is allowed to trip the tie circuit breaker and closes the affected main circuit breaker. No synchronization is needed because the bus will be dead.

### B. Automatic Transfer/Retransfer

The panel switches or HMI must enable automatic operation from the tie circuit breaker relay. The relay sends GOOSE messages status indicators to both main circuit

breaker relays that the automatic transfer mode is enabled. See Fig. 9. Safety mandates that manual operation should remain available during automatic MTM scheme operation and automatic scheme operation should disengage for any system abnormality.

#### 1) Automatic Transfer:

A number of conditions must exist for the system to run in automatic transfer mode. See the logic in Fig. 12. These conditions are the following:

- There are no power system faults
- IEC 61850 health is good
- The main sources are live
- The main circuit breakers and tie circuit breakers are trucked in
- The two main circuit breakers are closed
- The tie circuit breaker is open
- Breaker failure (50BF) has not been declared for any circuit breaker

Relay panel or HMI switches control the automatic transfer and automatic retransfer inputs to the tie circuit breaker relay as shown in Fig. 9 and Fig. 1.

An automatic transfer begins when either of the main sources goes dead (27 asserted) and there is no power system abnormality condition (50/51, 50BF, and 87 not asserted). GOOSE messages communicate these element statuses among the relays. Fig. 13 gives a view of some of the protection logic needed.

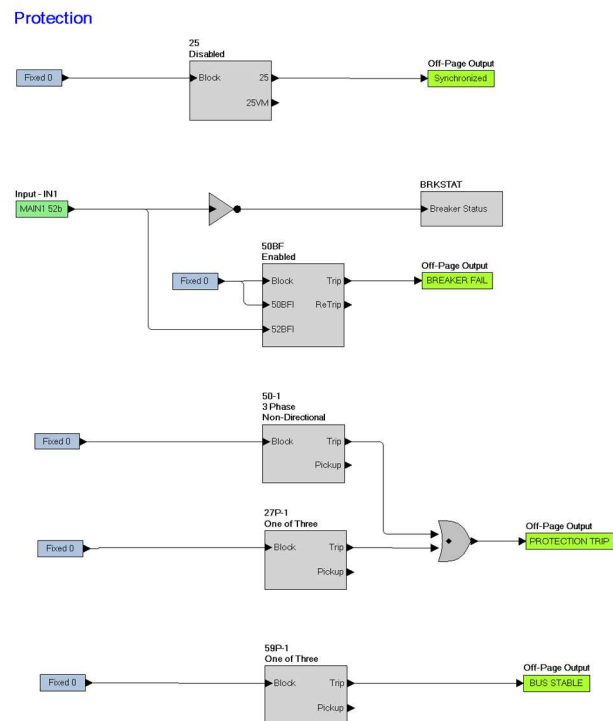


Fig. 13 Sample Protection Elements

The dead-source relay opens the associated main circuit breaker, seals-in the breaker from reclosing and sends a close command via IEC 61850 GOOSE to the tie circuit breaker relay (because motors on the bus are still running and producing a bus voltage, bus synchronism is necessary). A fast motor bus transfer can occur if the process occurs within 10 cycles or 170 ms (50 ms at 60 Hz for control signals, plus breaker close time), as previously discussed. Upon receiving the close command the tie circuit breaker relay waits to close for the transfer delay, then closes the tie circuit Breaker and seals-in the close at sync. The system now has one live main source powering both buses through the tie circuit breaker.

2) Automatic Retransfer:

As in the manual retransfer, an automatic retransfer must occur only if IEC 61850 communications health messages are satisfactory, and no faults exist on the power system.

a) Closed-transition automatic retransfer:

The system must be in the automatic mode (with open seal-in logic on the affected main circuit breaker relay and close seal-in logic on the tie circuit breaker relay). Fig. 14 gives a view of the logic needed to perform this retransfer in the affected circuit breaker relays.

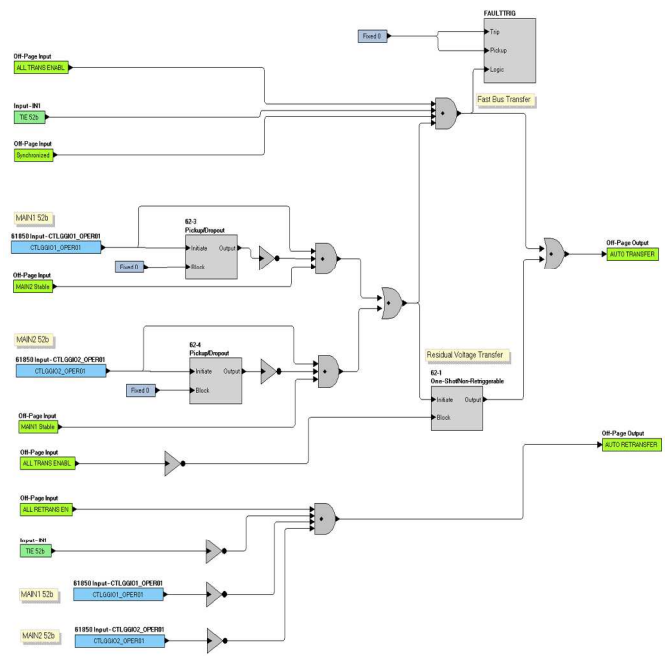


Fig. 14 Automatic Retransfer Sample Logic

The tripped main source relay must sense a good, live voltage on the tripped main source (and have no 87 differential trip from the main source transformer).

The tripped main relay checks for GOOSE messages from the other relays that the buses have no faults. The tripped main circuit breaker relay performs a sync check, closes the

main circuit breaker, and broadcasts a GOOSE message. If done quickly, a fast motor bus retransfer occurs. After the delay, the tie circuit breaker relay opens the tie circuit breaker. In this manner the potentially affected bus does not experience a power loss that would occur in an open-transition automatic retransfer.

3) Open-Transition Automatic Retransfer:

The system must be in the automatic mode. The main source voltage must be live and there is no 87 differential trip from the main transformer so that the main circuit breaker can close; relay logic and GOOSE messages confirm this situation. The automatic system begins with the tie circuit breaker relay tripping the tie circuit breaker and sending a GOOSE message to close the affected main circuit breaker. No synchronization is needed because the bus will be dead, assuming connected motors and reactors have ceased bus voltage contribution.

IV. MAIN SOURCES SEQUENTIAL FAIL HOLD

It is possible that both sources can fail one after the other. The MTM scheme must have the ability to hold (wait) for a good source if the main sources fail in succession.

For example, if an automatic transfer caused by losing source Main 2 is underway, then the Main 2 circuit breaker relay opens the Main 2 circuit breaker, sends the tie circuit breaker relay a close GOOSE message and the Main 1 circuit breaker should remain closed. However, without special transfer hold logic, if the Main 1 source is subsequently lost during this operation, the Main 1 circuit breaker would open. However, opening the Main 1 circuit breaker should not occur; the Main 2 circuit breaker is already open and opening the Main 1 circuit breaker causes more circuit breaker operational wear. Because there is no good source to which to transfer the load, the scheme should go into a holding mode and keep the Main 1 circuit breaker closed.

If the Main 2 source returns before the Main 1 source, then the Main 2 circuit breaker relay sends a GOOSE message to perform a seal-in trip of the Main 1 circuit breaker (to prevent paralleling main sources) before closing the Main 2 circuit breaker and sends a GOOSE message to perform a seal-in close of the tie circuit breaker if not already done (there is no closed transition in this scenario because both main sources have been out).

If the Main 1 source returns first then the Main 1 circuit breaker relay confirms the close on the Main 1 circuit breaker and sends a GOOSE messages to the Main 2 circuit breaker relay and tie circuit breaker relay to continue with the seal-in open of the Main 2 circuit breaker and seal-in close of the tie circuit breaker, and lift the hold.

## V. CONCLUSIONS

Using the IEC 61850 standard replaces relay/copper wire hardwiring between relays. GOOSE messages give similar performance and surpass the timing of copper connections.

The IEC 61850 MTM scheme is more secure because traditional copper wire connections can fail with no notice; however, if an IEC 61850 connection fails, the system sends immediately alerts because of the loss of GOOSE system health messages.

Implementing this standard leads to real cost reductions. Changes or tweaks in the MTM system are made easily; GOOSE messages and publishing/subscriptions are software changes (no rewiring).

Existing relay PT and CT connections and relay elements provide speed and simplicity. Elements important for a successful MTM scheme are 87, 25, 27, 59, 50, 51, 50BF. With newer equipment there is possible implementation with existing three-relay systems, PTs and protection elements because the IEC 61850 protocol might be an available option.

Fast motor bus transfer for keeping motor loads running is possible with a sufficiently fast MTM scheme, fast synchronization and fast-closing circuit breakers. In-phase transfers should be modeled and evaluated for possible operation. Residual transfers on a motor bus are certainly possible.

Operational modes are manual transfer, manual retransfer, automatic transfer, and automatic retransfer. Closed and open transition designs affect the type and number of GOOSE message communications, plus the internal relay logic. IEC61850 GOOSE messages can supervise manual transfers/retransfers, increasing safety.

Save circuit breaker wear by placing a hold on the scheme when main sources fail sequentially.

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## VII. CURRICULUM VITAE

Daniel (Dan) Ransom, PE has 40 years of industrial and utility electronics experience; including many years in motor protection development and application support. He has extensive experience in consulting engineering for power and communications systems. Dan is an engineering graduate (BSEE) of Gonzaga University, Spokane, Washington; he also holds a liberal arts degree from Washington State University. He is a member of the IEEE IAS (Industry Applications), PES (Power Engineering), Communications, and Standards societies. To date he has one US patent. He is a Professional Electrical Engineer in numerous states. Dan joined Basler Electric in 2010 and is Principal Application Engineer for the West Coast region.

Christopher Chelmecki received a B.S. degree in Computer Engineering from the University of Illinois, Urbana-Champaign, IL, in 2002. He is on track to receive his M.S. degree in Computer Science from Southern Illinois University, Edwardsville, IL in 2012. His Master's focus has been on Networks and Network Security with time spent researching modern advances in honeypot technology and the Zero Leak Architecture. He has worked in the Firmware Department at Basler Electric since 2004, currently as a Senior Software Engineer. He has worked on a diverse set of products including numerical relays, digital genset controllers, and photovoltaic inverters using network technologies such as Ethernet, RS-485, and CANbus, Modbus, and IEC 61850. He has received IEC 61850 training from SISCO. He has designed application protocols utilizing TCP/IP, UDP, and UART communications and debugged communications errors both in product development and in the field.