Preserve High-Speed Protection During Bypass Operations

J. Gastón Ortega and Elijah Nelson
Schweitzer Engineering Laboratories, Inc.

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***Abstract*—Many of the faults associated with breaker bypass and transfer operations occur during the switching process itself and are due to human error. Operators have the physical ability to create bus-to-ground faults while intending to isolate and bypass a line circuit breaker.**

In main/transfer, and single-breaker double bus arrangements, protection communications are difficult to preserve during breaker-bypass operations. Line current differential (87L) protection, however, is never preserved during the entire breaker-bypass process due to the resulting parallel current paths that feed the protected line through both line and transfer breakers. On schemes implementing 87L protection, the protection typically is disabled during the entire bypass process and temporarily replaced by a step-distance protection scheme, compromising the quality of protection when it is needed the most.

The focus of this paper is to present three complete solutions to this problem by maintaining the original protection integrity during the bypass process, using a three-terminal line concept, and using a communications transfer switch to preserve line current differential protection and minimize installation costs.

I. Introduction

Main/transfer, and single-breaker double bus arrangements were first built in Europe in the early 1900s to be able to transfer the bus feed onto a line or feeder without de-energizing the load.

The main/transfer bus arrangement provides a low-cost solution for switching lines to a transfer or auxiliary bus, usually to perform maintenance on the line breaker. The transfer bus is rated to feed only one serviced line at a time. It has been implemented mostly in America, and it is preferred on industrial applications for its practicality and low cost.

The single-breaker double bus arrangement has two main buses that are equally rated. This arrangement potentially allows the station to feed all of its lines through either of its two buses, increasing power availability in case of bus faults. This arrangement is most popular in Europe with electrical utilities. Line current differential (87L) protection offers excellent security and dependability on well-defined protection zones. It operates with very few settings, requires only current signals, and is unaffected by voltage inversions or out-of-step conditions [1]. Its main disadvantage is vulnerability to communications channel breakdowns.

The aforementioned bus arrangements are designed to bypass the line breaker with the transfer breaker whenever necessary. Bypass operations often require a local on-site operator to follow a meticulous switching process and to visually verify that disconnect switches have positioned themselves correctly during the entire process [2]. In practice, whether via local or remote control, it is common to see faults during these operations that are accidentally caused by the operators.

The pie chart in Fig. 1 shows the distribution of bus faults considered in a study led by G.E.C. Measurements in 1975 (as cited in [2]), recognizing that it is likely that a fraction of these faults occurred “as a direct result of manual high voltage switching operations.”

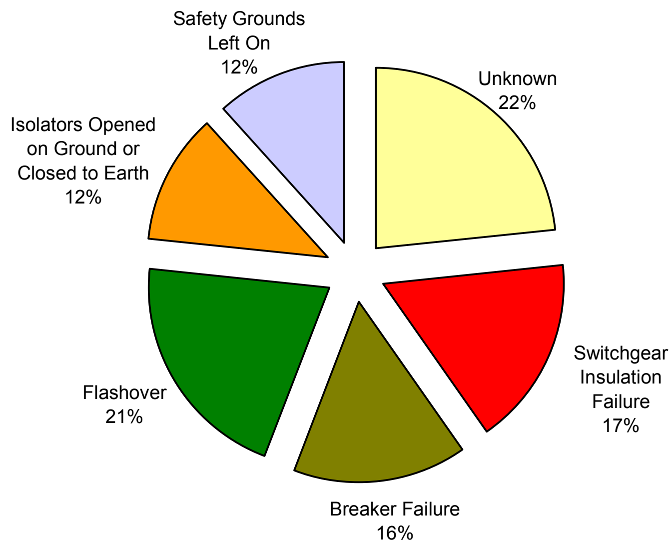

Fig. 1. Study of 129 Bus Faults

Typically, the system configuration on these buses uses a transfer (or coupler) breaker and several local breakers to protect the energized lines (Fig. 2). During breaker maintenance in these substations, it is imperative to bypass the breaker to keep the line energized and protected at all times. In this paper, everything discussed with main/transfer bus arrangement also applies to most single-breaker double bus arrangements.

During bypass operations, these bus arrangements impede keeping 87L protection active. Under normal operating conditions, local and remote relays communicate with each other, implementing a two-terminal 87L element to maintain a protection zone. Ideally, during a bypass operation, it is desired to preserve both power and high-speed (87L) protection. The ability to provide uninterrupted 87L protection during bypass operations significantly improves the protection reliability of single-breaker double bus, and of main/transfer bus systems.

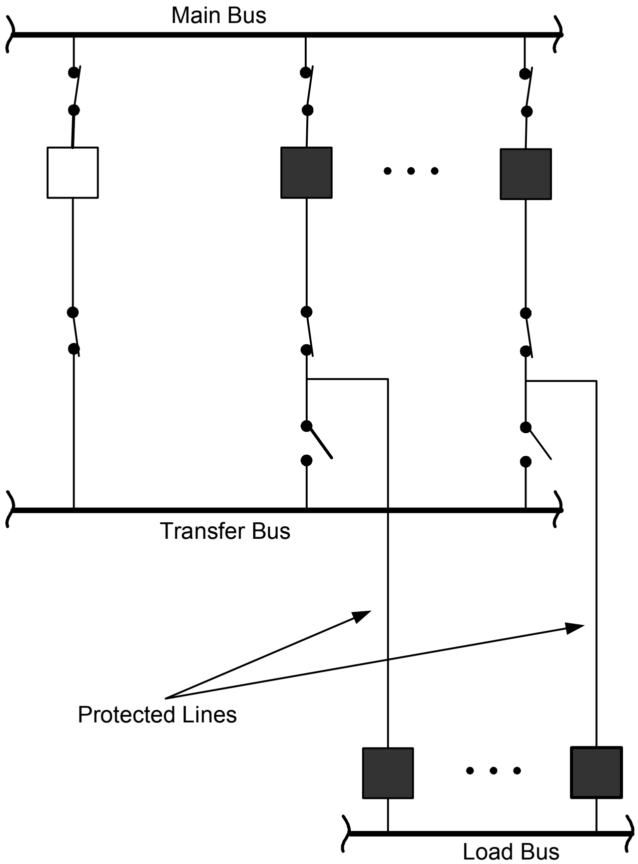

Fig. 2. Typical Main and Transfer Bus Arrangement

To preserve the power on the line during the bypass of a local breaker, the transfer relay is brought into service and the transfer breaker is closed, creating a parallel current path within the bus system feeding the protected line. For this reason, 87L protection communication is sometimes disconnected during the entire bypass operation, and the protection is downgraded to a secondary, less efficient alternative, such as step-distance protection (see “Backup Protection” in Fig. 3).

A widely accepted solution is to use a mechanical switch to select the current transformer (CT) cables, normally coming from the local breaker into the local relay but rerouted to the same relay from a transfer-breaker CT when the local breaker is out of service. For this method, 87L is disconnected only during the high-voltage switching process (see “CT Connections Rerouting” in Fig. 3).

A more recent practice to this difficult situation has been to disable the 87L element, leaving step-distance protection during the manual high-voltage switching process, and use a communications transfer switch to reroute the remote 87L communications channel to the transfer relay, preserving 87L protection during the breaker-bypassed state (see “87L Communications Rerouting” in Fig. 3).

On the other hand, if 87L protection were preserved throughout the switching process, the system would have the highest level of security and dependability during its most vulnerable process (see “Three-Terminal Line Solutions” in Fig. 3).

To preserve 87L protection during the high-voltage switching process of a bypass operation, a local, remote, and transfer relay need to communicate with each other to avoid false trips due to splitting currents. Once the bypass to the transfer relay is completed, the local breaker is taken out of service, letting the transfer breaker feed the full load of the protected line. The transfer and remote relays then need to preserve 87L communication.

A. Definitions

For the purpose of this discussion we will define a relay located in the local substation, normally controlling and monitoring a line breaker, as the local relay. The relay that controls the breaker used to bypass the local breaker is called the transfer relay. The transfer relay controls the transfer breaker that ties the two buses together through disconnect switches. The remote relay controls the breaker at the remote end of the 87L protection zone. The methods described in this paper use a local, transfer, and remote relay in a three-terminal relay communications system.

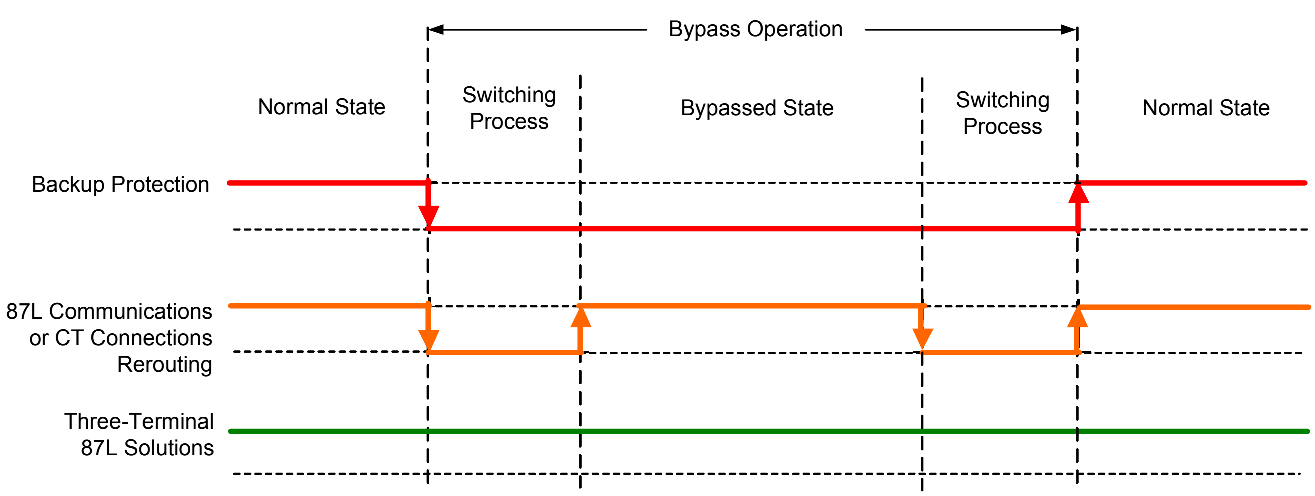

Fig. 3. Bypass Operations—When Is 87L Active?

As defined in this paper, a main/transfer bus arrangement has a transfer bus rated to carry the load of only one power line at a time. A single-breaker double bus arrangement has both buses rated to withstand the full load of all power lines.

A bypass operation, in this paper, refers to the process of creating an alternate current path to feed and protect a power line in order to take the local breaker out of service, for maintenance or due to failure.

A transfer operation, in this paper, is the process of transferring protection communication to and from the transfer relay.

B. Solutions

This paper presents three solutions for consideration, with individual advantages and disadvantages, which depend on the equipment and resources available. The common advantage of these three solutions is that they all preserve 87L protection during the breaker-bypass process and after the breaker is bypassed. Counting on 87L protection at all times greatly improves the reliability of the line protection. The solutions range from standard to a new enhanced form of three-terminal line current differential protection.

The first solution uses both the transfer and the local relay as masters at separate times—when bypassing and when reestablishing the normal configuration, respectively. In addition to the 87L communications channel, this solution requires an additional channel between the local and remote relays to change remote relay settings, and to set up an 87L three-terminal system mastered by the local relay. This will aid the transition of protection from the transfer breaker back to the local line breaker.

The second solution uses the transfer relay as the permanent master, which eliminates the need for an additional communications channel. Both local and remote relays need to become slaves by changing their settings from a two- to a three-terminal line.

The third solution describes a new three-terminal line system using a coordinating relay and no slave relays, for which a patent has been applied. This system reduces installation costs and minimizes commissioning time. Local and remote relays do not need to change their settings from two- to three-terminal 87L slave relays during the bypass process.

These solutions can be implemented at a substation with multiple power lines or feeders by means of a communications transfer switch [3] that provides for manual or automatic switching of the 87L protection channels.

II. Preserve Line Current Differential Protection at All Times

A. Standard Three-Terminal Line Current Differential Solution 1—Two Masters, Two Remote Communications Channels

This method offers continuous 87L protection using two relays as masters at different times, four 87L communications channels, one relay-to-relay digital channel, and four settings groups on local and remote relays during the bypass process. During the transfer from the initial state to the bypassed state, the transfer relay acts as the master to coordinate 87L protection and change remote relay settings from a two- to a three-terminal mode. When transferring back from the bypassed state to the normal state, the local relay becomes the master to coordinate the 87L protection and to change settings in the remote relay back to a two-terminal mode.

This method is described as a five-step process while the switching operation moves from the normal condition (line breaker protects the line), to the bypass condition (transfer breaker protects the line), and back to normal. The process begins with the current flowing from the main bus, through the local and remote breakers, and on to the load bus.

In the initial state, both the local and the remote relays are in two-terminal mode, coordinating 87L protection through one communications channel, while the transfer relay is not operating in the system (Fig. 4). Before the transfer bus is brought into service, it is energized to ensure that there are no faults.

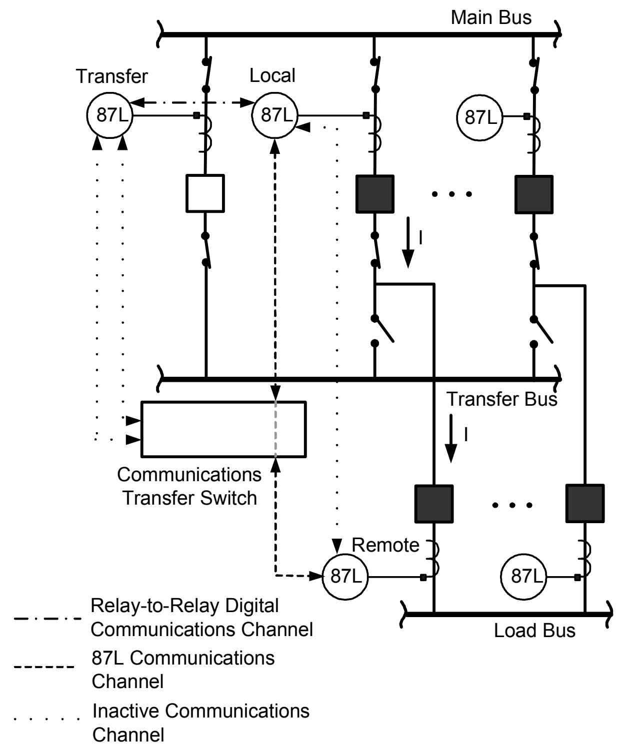

Fig. 4. System Configurations Before Switching Operation

In the second state, relay settings groups are changed manually or automatically on all three relays (transfer, local, and remote) to create a three-terminal 87L protection system. Because the transfer relay is set as a master, two communications channels connect to this relay to establish the 87L protection communication with the local and remote slave relays. The operator closes the corresponding transfer disconnect switches and breaker. This operation splits the current flow through both the local and the transfer breakers, keeping 87L protection active (Fig. 5).

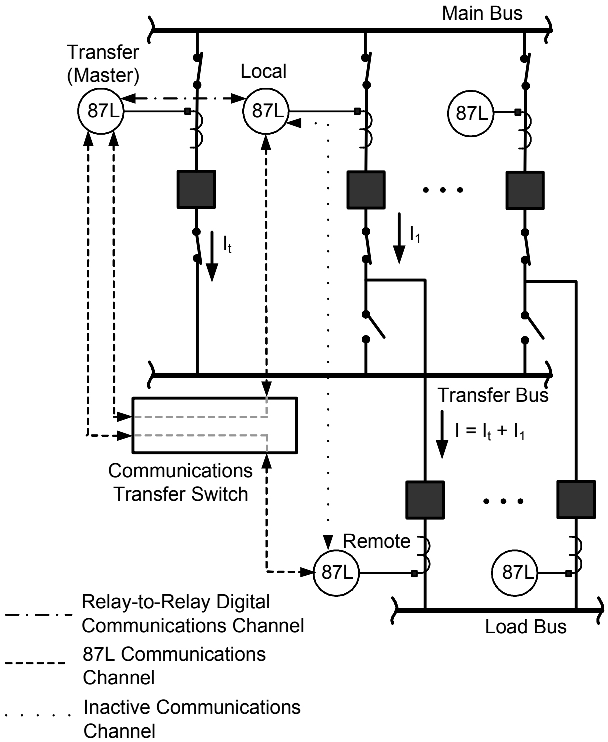

Fig. 5. Transfer Relay as Master for Switching Operation

In the third state, the local breaker and switches are opened to let the local breaker be removed from service. The transfer and remote relays switch settings groups to coordinate a two-terminal 87L protection (Fig. 6). The system protection may stay in this state as long as it is necessary for maintenance or repairs of the local breaker.

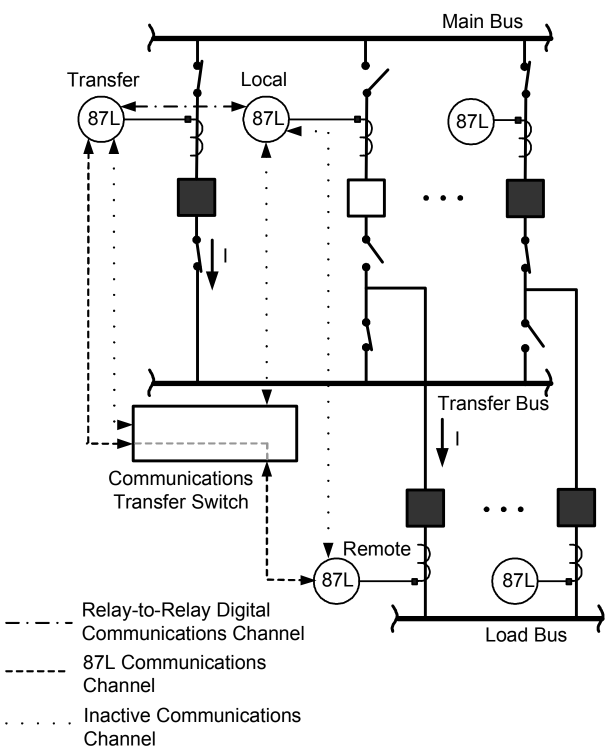

Fig. 6. Local Relay Bypassed

Note: If a three-terminal 87L system were maintained during the bypassed state while the local relay measures zero current, it would still protect the bypassed line. However, the accidental turning off of the local relay or settings change when the local breaker is out of service is likely to happen and would interrupt the 87L protection. This is why it is best practice to switch the transfer and the remote relays into a two-terminal 87L mode.

The fourth state starts when the need for the bypass is satisfied and the local breaker can be brought back to service. This state is similar to the second state, but the local relay is set as the master instead of the transfer relay. The local relay is placed back in service to coordinate a three-terminal 87L protection scheme and the remote and transfer relay are switched to three-terminal slave mode. Once more, this will allow maintaining the power and preserving 87L protection with parallel current paths in the bus. In this configuration, the local relay (set as the master) is using two communications channels to coordinate three-terminal 87L protection (Fig. 7).

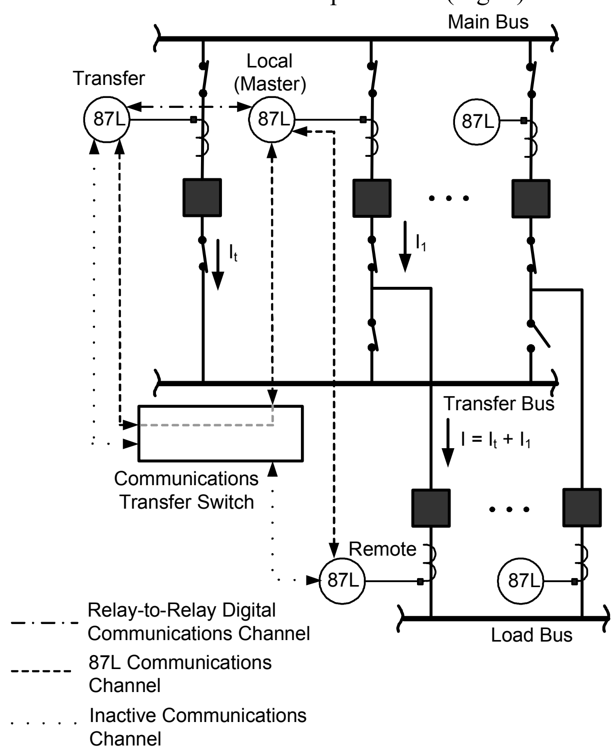

Fig. 7. Local Relay as Master for Switching Operation

The fifth state removes the transfer relay from the system to let all of the current flow through the local breaker. The local master relay changes the remote relay settings and then its own, to coordinate a two-terminal 87L protection zone with the remote relay. At this point, the transfer breaker is typically isolated from the system. The bypass process is now complete and the system has been returned to the initial state with the local and remote relays coordinating 87L protection in two-terminal mode (Fig. 4).

1) Advantages and Disadvantages

When the line has backup protection schemes using communication, the additional 87L communications channel between the local and remote relay might already be installed and available to change settings during the bypass process. In this case of having backup systems, the additional channel does not translate into additional costs.

One of the disadvantages of this method is that the protection scheme requires two communications channels on each relay to coordinate the 87L protection and one additional relay-to-relay digital channel to provide settings control between the local and transfer relays. The additional communications channel is necessary due to the fact that the 87L communications ports in the transfer relay are initially inactive. The same occurs to the local relay when transferring back from the bypassed state. As a result of the need for an additional communications channel, there will be additional costs involved in the installation.

Another disadvantage of this method is that each relay needs four different settings groups to accommodate the group change requirements. Although manual or automated implementation is easy to achieve, these requirements add additional complexity to the initial commissioning.

As it is presented next in Solution 2, Solution 1 can more quickly transition the two-terminal 87L protection scheme from the bypassed state into a three-terminal 87L scheme mastered by the local relay. Other advantages apply if the transfer is the master relay during the return to the normal state. However, with the transfer as master, 87L protection is unavailable for a longer period of time while changing relay settings. In conclusion, this first solution contains higher costs but it is more dependable.

B. Standard Three-Terminal Line Current Differential Solution 2—One Master, One Remote Communications Channel

In this second solution, the transfer relay is set as the master during the bypass process, using one remote communications channel and three settings groups in the local and remote relays.

In the initial state, the two-terminal 87L protection is coordinated between the local and remote relays. At this point, the current is flowing from the main bus, through the local and remote breakers, and on to the load (Fig. 8).

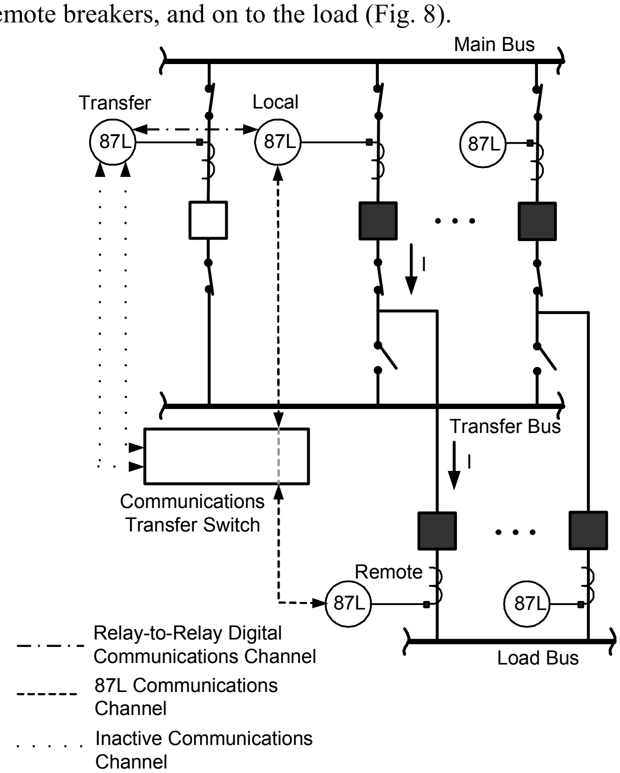

Fig. 8. System Configuration Before Switching Operation (Solution 2)

To begin the bypass process in the second state, and to ensure that there are no faults on the transfer bus, the transfer relay is set as master to coordinate a three-terminal 87L protection scheme, and the local and remote relays are set as slaves in three-terminal mode. To initiate the three-terminal 87L protection scheme, the local relay changes the settings group of the remote relay over the 87L communications channel and the settings group of the transfer relay over a direct channel using relay-to-relay digital communication. The transfer breaker is then closed (Fig. 9).

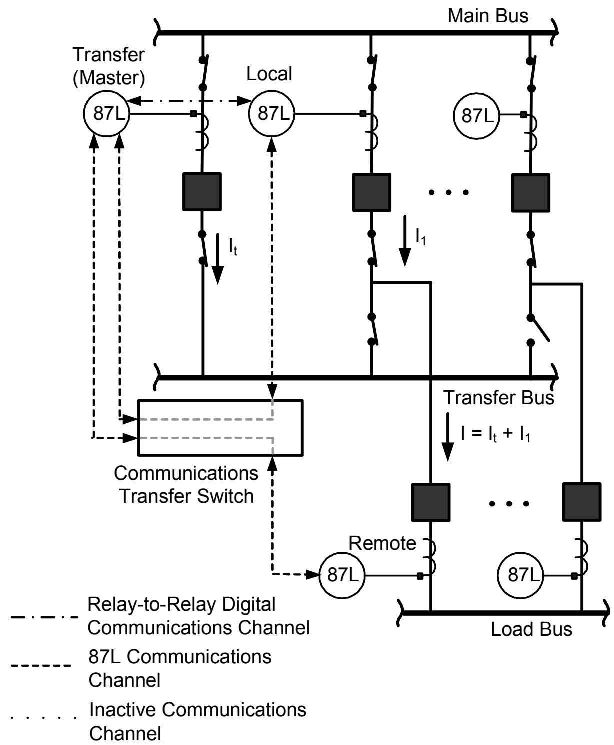

Fig. 9. Switching Operation Configuration

At this point, there are two parallel current paths on the local side of the 87L protection zone. Without a three-terminal arrangement, conventionally, 87L protection would be disconnected and step-distance protection would be implemented during the process.

The third state is to open and isolate the local breaker, which is no longer required in the system. When the local breaker has been taken out of service, the current flows through the transfer and remote breakers and on to the load (Fig. 10). The transfer and remote relays can now switch from a three- to a two-terminal 87L protection zone. The transfer relay changes group settings on the remote relay through the 87L communications channels. The system can remain on this state as long as it is necessary and will continue to have 87L protection.

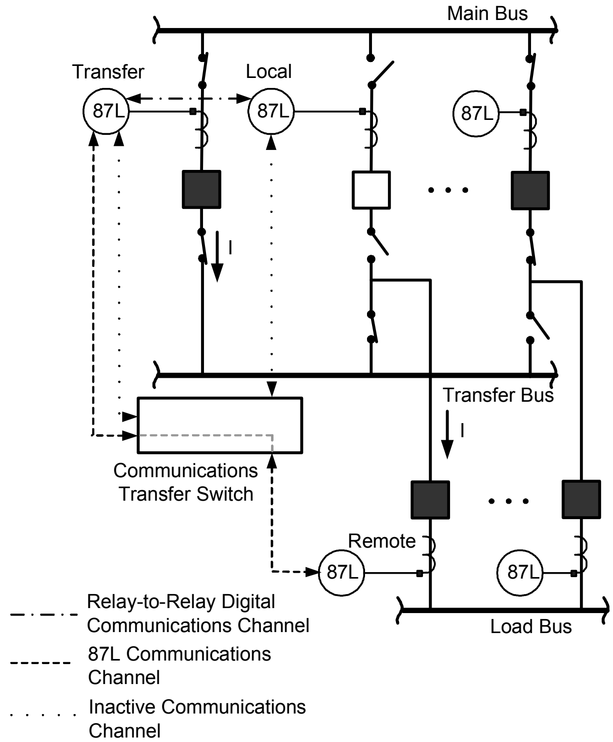

Fig. 10. Local Relay Bypassed State

In the fourth state, when the bypass is no longer needed and the local breaker and relay can be placed back in service, the transfer relay will set up a three-terminal 87L protection scheme, to allow the transition of 87L protection zones. First, the transfer relay changes the local relay settings through a digital communications channel. Next, the transfer relay changes its own settings to become the three-terminal 87L master relay (primary protection is momentarily lost at this time), and finally it uses its newly activated 87L communications channel to change the remote relay settings group to make it a slave relay (primary protection is recovered). Depending on the relay manufacturer, this process could take a few milliseconds. The local relay settings group cannot be changed through the 87L communications channel at this time because the local relay has had its 87L communications port deactivated since the previous state (Fig. 9).

The fifth state is finished when the transfer breaker is opened, letting the local and remote relays coordinate the original two-terminal 87L protection zone. The transfer relay can simultaneously change the settings groups of the local relay through the direct channel and the remote relay through the 87L communications channel, dropping the three-terminal line arrangement to return the system to the initial state (Fig. 8).

1) Advantages and Disadvantages

This second method preserves the 87L protection during the entire bypass process and has the added advantage of doing this in a more economical manner than the first method. The configuration of the second method depends on fewer communications channels. There is no need for an additional 87L channel between the local and remote relays. This brings important savings, especially if the system does not include multiplexers between substations.

To minimize the number of communications channels, it is important to use the same 87L channels to also change relay settings groups wherever possible. In some cases it is necessary to use additional channels because some 87L channels may be disabled under some system configurations.

The implementation of a communications transfer switch further minimizes the number of communications channels per line, and it allows a straightforward communications transfer from multiple local and remote relay pairs onto the transfer relay.

The first disadvantage of this solution is that 87L protection is momentarily lost (for settings changes), but for a period longer than Solution 1, when creating the three-terminal line and to return the system to normal from the bypassed state. This translates into a slightly less dependable solution than the first method.

One shortcoming that this design has in common with the previous configuration is that the system requires several settings groups in each of the relays. If relay settings group changes were unnecessary, installation costs would be even lower due to fewer communications channels. The next solution addresses this issue in detail.

C. Enhanced Three-Terminal Line Current Differential System Solution 3—One Master, No Slaves, Zero Settings Changes, and No Extra Communications Channels

A multiple-terminal line system, for which a patent has been applied, is the third, most cost-effective solution for this paper; it is implemented as a three-terminal line system.

The same three-terminal line concept can be generalized to a multiple relay system, as long as there are physical means for a coordinating relay to exchange information with multiple relays.

1) General Coordination Concept: Multiple-Terminal 87L System

A multiple-terminal 87L protection system is coordinated by one relay, which simultaneously establishes and handles multiple two-terminal 87L protection zones with several relays. This new concept requires no change to protection settings on any local or remote relays during a bypass process.

As shown in Fig. 11, the coordinating relay, R_x, measures its local current, I_x, and receives current quantities (phasors I_1, I_2, I_3, I_4,…,I_n) from all connected relays (R_1, R_2, R_3, R_4,…,R_n). Each single quantity sent out to each connected relay by the coordinating relay is the vector sum (magnitude and phase angle) of its own current measurement plus all other current quantities received (except for the current sent by the relay receiving this total vector quantity). Each of the multiple relays that are connected to the coordinating relay and use a two-terminal 87L element will perform the vector sum of the quantity received from the coordinating relay and their own measurement. The relays will find the vector sum equal to zero whenever there is no fault in the multiple-terminal 87L protection zone created by all relays involved, including the coordinating relay.

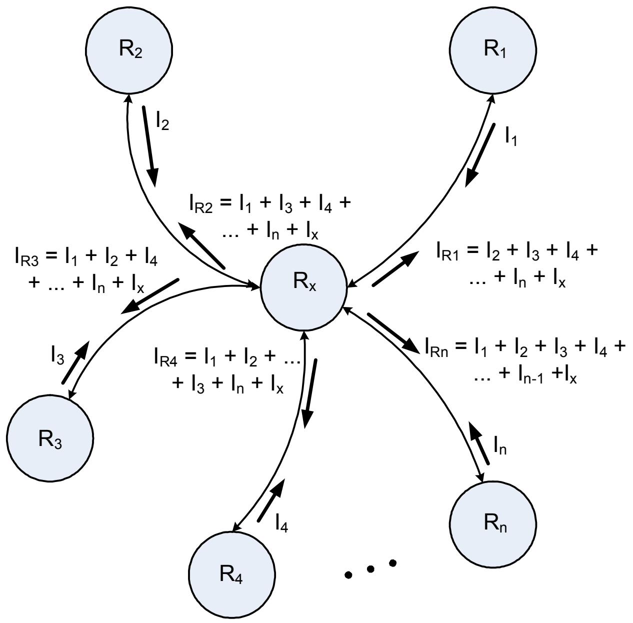

Fig. 11. Enhanced Multiple-Terminal 87L Protection System

The coordinating relay "tricks" the connected relays to "believe" they are protecting only one line with a two-terminal 87L protection element, when they are actually part of a multiple-terminal protection zone. In addition, the coordinating relay evaluates an 87L element using the vector sum of all received quantities and its own current measurement.

Fig. 12 shows the flow chart of a coordinating relay that uses this principle to coordinate multiple-terminal 87L protection communications. A coordinating relay, R_x, communicates with each of the multiple relays, R_1 to R_n, in the system presented in Fig. 11.

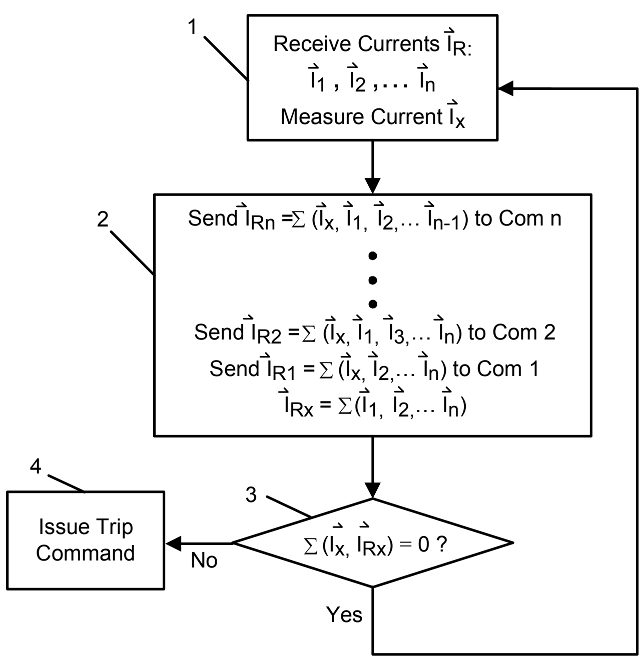

Fig. 12. Flow Chart of Coordinating Relay

The following steps explain the flow chart in Fig. 12 of the system represented by Fig. 11.

Step 1: A coordinating relay (transfer relay R_x in our solution) establishes a respective two-terminal 87L protection scheme with each of several relays by receiving time-aligned current vector quantities, I_1 through I_n, from all line ends in the system through respective communications channels or respective communications ports, Com 1 through Com n.

Concurrently the coordinating relay measures its local current vector quantity, I_x, through its current transformer (CT).

Step 2: The coordinating relay includes relay settings communicating a respective remote current, I_R, to respective communications channels or communications ports Com 1 through Com n; where the respective remote current is the vector sum of all other currents except for the current of the respective relay.

For example, the coordinating remote relay current, I_{Rx}, vector sum as $\Sigma(I_1, I_2, \ldots I_n)$; the remote Relay 1 current, I_{R1}, vector sum as $\Sigma(I_x, I_2, \ldots I_n)$ to port Com 1; the remote Relay 2 current I_{R2} vector sum as $\Sigma(I_x, I_1, I_3, \ldots I_n)$ to port Com 2 and the remote Relay n current, I_{Rn}, vector current sum as $\Sigma(I_x, I_1, I_2, \ldots I_{n-1})$ to port Com n etc.

Step 3: Simultaneously, each of the several remote relays applies a two-terminal 87L element by checking its measured current with the respective remote current, I_R, for a new vector sum to zero.

For example, the coordinating relay checks $\Sigma(I_x, I_{Rx})$ vector sum to zero, while Relay 1 checks $\Sigma(I_1, I_{R1})$ vector sum to zero, and Relay n checks $\Sigma(I_n, I_{Rn})$ vector sum to zero, etc. If the vector sum is zero, there is no internal line fault, and the relay continues to repeat the operation starting in Step 1. If the vector sum is not zero, an internal fault is indicated by the relay by issuing a trip command in Step 4.

Step 4: Relay issues a trip command, if vector sum is not zero, to indicate an internal fault.

2) Enhanced Three-Terminal 87L System

87L protection stays active during a bypass operation, without changing local or remote relay settings groups, by applying the enhanced three-terminal 87L system. This new concept becomes an enhanced 87L protection setting in the transfer relay, as opposed to a standard three-terminal 87L setting. The transfer relay simultaneously establishes a respective two-terminal 87L protection communication with a local relay and with a remote relay, separately, forming a special three-terminal line arrangement where no relay settings group changes are required during bypass operations (Fig. 13).

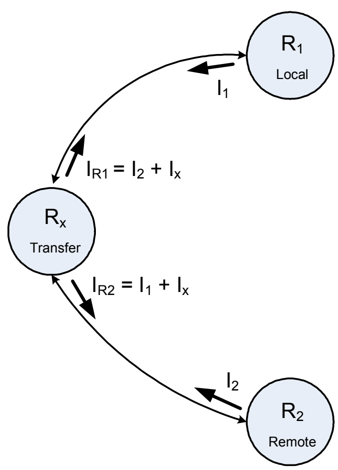

Fig. 13. Enhanced Three-Terminal 87L Protection System

In this way, the transfer relay coordinates a three-terminal 87L protection zone with a local and remote relay, protecting the temporary parallel current path created during the bypass process. This solution retains 87L protection before, during, and after a breaker bypass process, without changing local or remote relay settings groups. Local and remote relay settings remain on a two-terminal line 87L mode while the bus-switching configuration changes from normal to bypass and vice versa (Fig. 14).

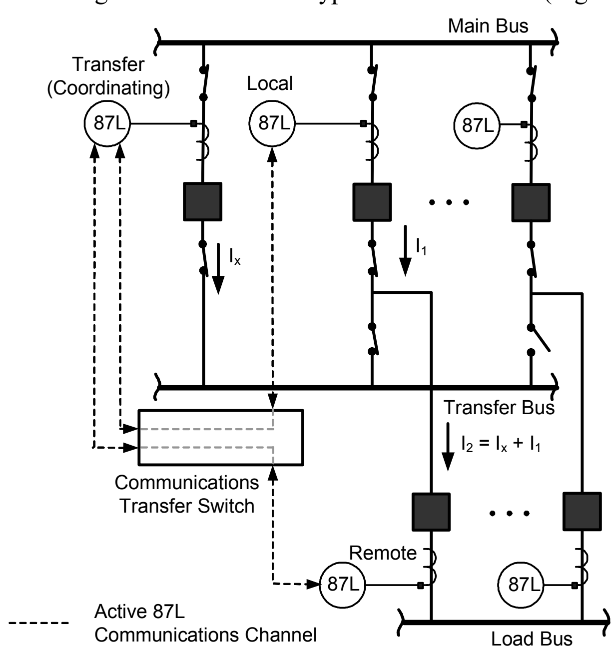

Fig. 14. Transfer Relay Coordinates a Three-Terminal 87L System Using Local and Remote Relays Set on a Two-Terminal Line 87L Mode

To allow automatic or manual transfer switching of multiple communications channels, the respective two-terminal 87L protection of local and remote relay pairs are facilitated through a communications transfer switch with multiple inputs and outputs.

3) Advantages and Disadvantages

The enhanced three-terminal 87L system is the most cost-effective solution presented in this paper. It minimizes commissioning and installation costs, while improving protection dependability at all times during bypass operations.

This application requires no settings group changes in the local or remote relays, which translates into minimal engineering labor time to set up the bypass system. A basic system with three relays (transfer, local, and remote) depends only on one remote communications channel.

The use of a multiple inputs and outputs communications transfer switch accommodates several local and remote relay pairs, applying either 87L or other relay-to-relay digital communications.

III. Conclusion

Due to the growing flexibility of the present multifunctional relay technology, not only is it possible to preserve line current differential (87L) protection during bypass operations on main/transfer bus, and single-breaker double bus arrangements, but there are several very safe, reliable, and economical implementations.

IV. References

[1] Guzman, Vargas, and Robles, "Underground/Submarine Cable Protection Using a Negative-Sequence Directional Comparison Scheme," Schweitzer Engineering Laboratories, Inc., INELAP-PQE, CFE, 1998.

[2] R. Whittaker, "The Hidden Economy of Cost Reduction Deleting a Power Circuit Breaker at Pearl Substation Increases Relay and Control Scheme Complexity," 26th Annual Western Protective Relay Conference, Spokane, WA, October 1999.

[3] J. Reidt, B. Heilman, "Using the SEL-2126 Fiber-Optic Transfer Switch and the SEL-321-1 in Bypass-Breaker MIRRORED BITS® Communications-Assisted Tripping Schemes," SEL application guide AG2005-09, Volume 2. Available: http://www.selinc.com/ag2.htm

[4] A. Risely, J. Roberts, and P. LaDow, "Electronic Security of Real-Time Protection and SCADA Communications," 5th Annual Western Power Delivery Automation Conference, Spokane, WA, April 2003.

[5] B. Heilman, "Using the SEL-2100 Logic Processor in Bypass Breaker MIRRORED BITS Communications-Assisted Tripping Schemes," SEL application guide AG2004-01, Volume 2. Available: http://www.selinc.com/ag2.htm

[6] K. Behrent, "Three-Terminal Line Protection Using SEL-321-1 Relays With MIRRORED BITS Communications," SEL application guide AG96-17, Volume 1. Available: http://www.selinc.com/ag1.htm

[7] J. Roberts, "Line Differential Protection System for a Power Transmission Line," U.S. Patent 6,590,397B2.

[8] E. Schweitzer III, G. Scheer, "Systems of Communicating Output Function Status Indications Between Two or More Power System Protective Relays," U.S. Patent 5,793,750B1.

V. Biographies

Juan Gastón Ortega has a B.S. in Electrical Engineering from Washington State University. He worked as a research assistant at Washington State University for the Advanced RF and Mixed-Signal Application Group and he was a teaching assistant at Washington State University. Gastón has broad international experience by living, studying, and pursuing his career in Argentina, Wales, the United States, and Mexico. He first joined Schweitzer Engineering Laboratories, Inc., in 2004 as an engineering intern. Gastón has participated in several IEEE PSRC groups since January 2006. He is now the Product Manager for communications products at SEL.

Elijah Nelson has a B.S. in Electrical Engineering from Washington State University. He worked on a collaborative senior design project with Schweitzer Engineering Laboratories, Inc., and Washington State University in 2005–2006 doing a relay retrofit study. He joined SEL in 2006 as a Marketing Intern and now holds the position of Product Manager.