Automatic High Voltage Bus Reclosing

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Introduction

Over the years, high voltage bus protection at Georgia Power was implemented using low impedance bus relays with telephone relay logic and in recent years a programmable logic controller (PLC) performing bus test/reclosing. This paper will review the installation of microprocessor-based low impedance bus protection relays. The bus test/reclosing logic was implemented within the programmable logic of the low impedance bus protection relay and will be reviewed in the paper. The paper will also review the why & how Georgia Power uses such test/reclosing logic on 115kV and 230kV straight buses.

High Voltage Bus Protection Philosophy

Georgia Power Company has used automatic testing of high voltage substation buses since the 1950's. The schemes are applied in 230kV and 115kV straight bus stations. The previous bus differential installations used a lockout relay that had to be manually reset at the station. It was hoped that temporary faults such as insulator flashovers would allow for automatic reclosing of the high voltage bus.

All the earlier designs used low impedance electro-mechanical bus differential relays with restraint and operate windings.

Distribution transformers were connected to the transmission bus through motor operated disconnect switches. Faults on the high voltage side of the transformer, within the bus differential protection zone, such as lightning arrestors or bushings could be isolated by opening the transformer motor operated disconnect switch.

The design needed to be flexible enough to accommodate high voltage buses with differing numbers of breakers and distribution transformers. The design needed to handle the tripping and control of distribution transformer faults.

The original design operation sequence is as follows:

1) The bus differential relay detects a fault on the high voltage bus.

2) All breakers surrounding the faulted zone are tripped.

3) The designated test breaker closes to test the bus:

    a) If the fault does not reoccur, the test breaker remains closed and all breakers are allowed to close and the load is restored.

    b) If the fault is still present when the test breaker closes, the test breaker will trip again and the motor operated disconnect switches will open to isolate any distribution transformers.

4) The test breaker will then close a second time:

    a) If the fault is now cleared the other transmission breakers will be allowed to close, restoring the transmission network. The breakers on the low voltage side of the distribution transformers will be kept open.

    b) If the fault is still present, the bus will be locked out and no further testing can occur until a person enters the substation and resets the differential scheme.

5) Any operation of the bus differential scheme will send an alarm to SCADA, and personnel will be immediately dispatched to the substation to check for damage to all equipment on the bus.

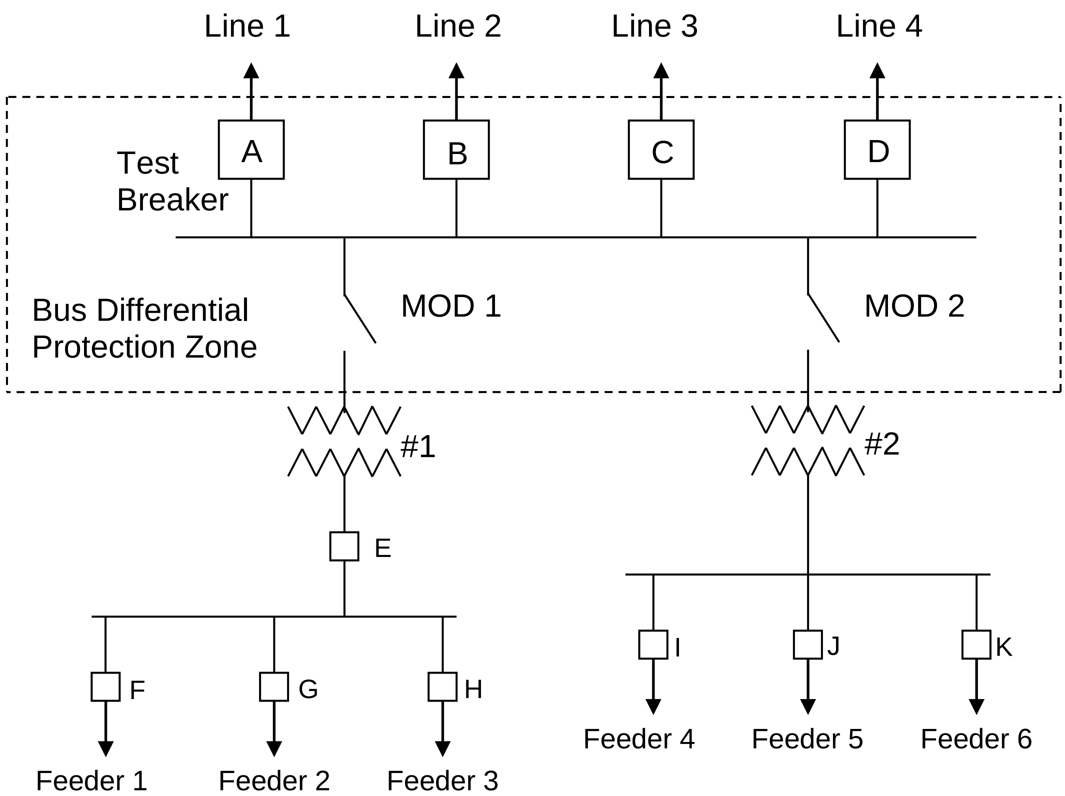

Figure 1 – Typical bus differential protection

Figure 1 above shows the typical bus differential protection zone covering the line side of the transmission line breakers to the bushing current transformers in the distribution transformers. This puts the transformer high voltage side lightning arrestors and transformer bushings in the bus differential protection zone. The distribution transformers will have transformer differential relays protecting the transformer but tripping the transmission breakers will be through the bus differential protection scheme tripping relays.

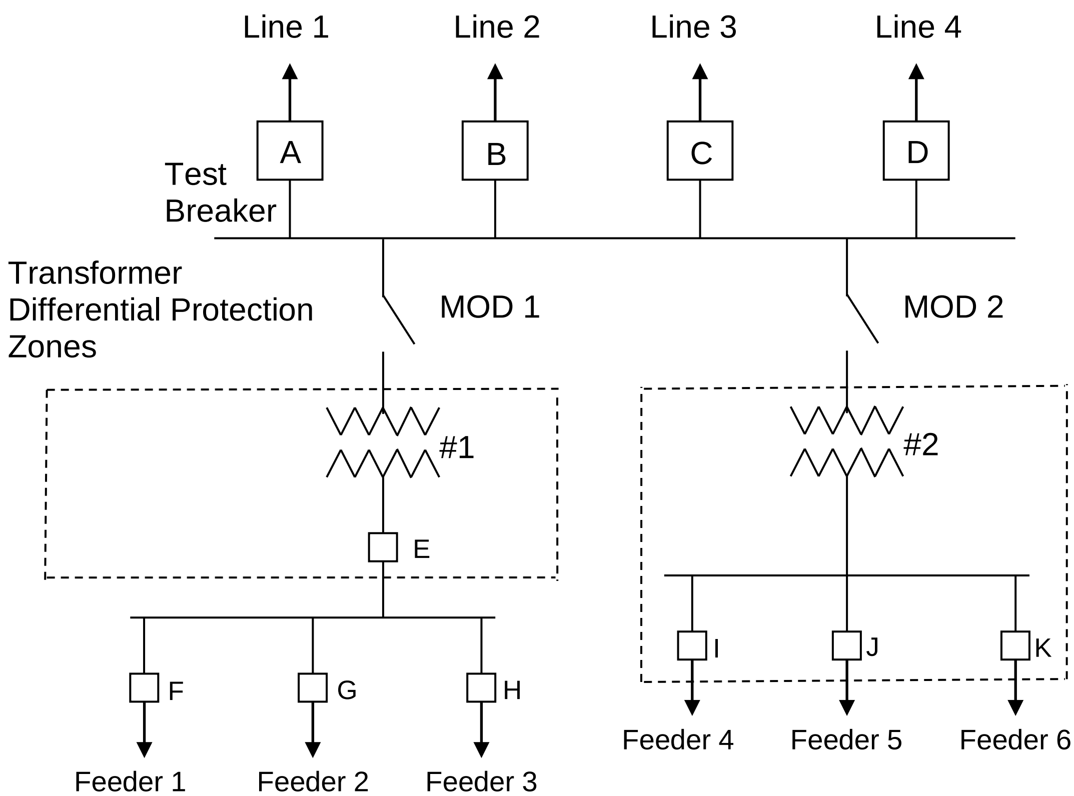

Figure 2 – Typical transformer differential protection zones

Figure 2 above shows the typical transformer differential protection zones covering the bus side of the transformer high voltage bushing current transformers to the bus side of the low voltage side breakers. This puts the transformer high voltage side lightning arrestors and transformer bushings in the bus differential protection zone. The distribution transformers will have transformer differential relays protecting the transformer but will open the transmission breakers through the bus differential protection scheme tripping relays.

For transformer #1 the protection zone only extends to the low side bank breaker E, because there is very little exposed bus on the low voltage side the chances of a fault being outside the transformer and thus temporary was judged to be small. Because of that automatic testing of the high voltage bus and transformer #1 would not be attempted. If a differential relay on transformer #1 operates MOD 1 will be opened before the test breaker closes to re-energize the high voltage bus. If the first test is unsuccessful MOD 2 on transformer #2 will open and the test breaker will close again. If the second test is unsuccessful the high voltage bus and both transformers will be locked out.

For transformer #2 the transformer low voltage bus extends all the way to the line side of the distribution feeders. Since there is a significant amount of exposed low voltage bus the chances of a fault inside the transformer differential zone but outside the transformer tank is greater, so the decision was made to test the transformer one time after a transformer differential. In this case if the transformer differential relays operate on transformer #2 the automatic testing of the bus will include re-energizing transformer #2. If transformer #2 differential operates a second time MOD 2 will be opened and the test breaker will close again to test the high voltage bus and transformer #1. If the second test is unsuccessful the high voltage bus and both transformers will be locked out.

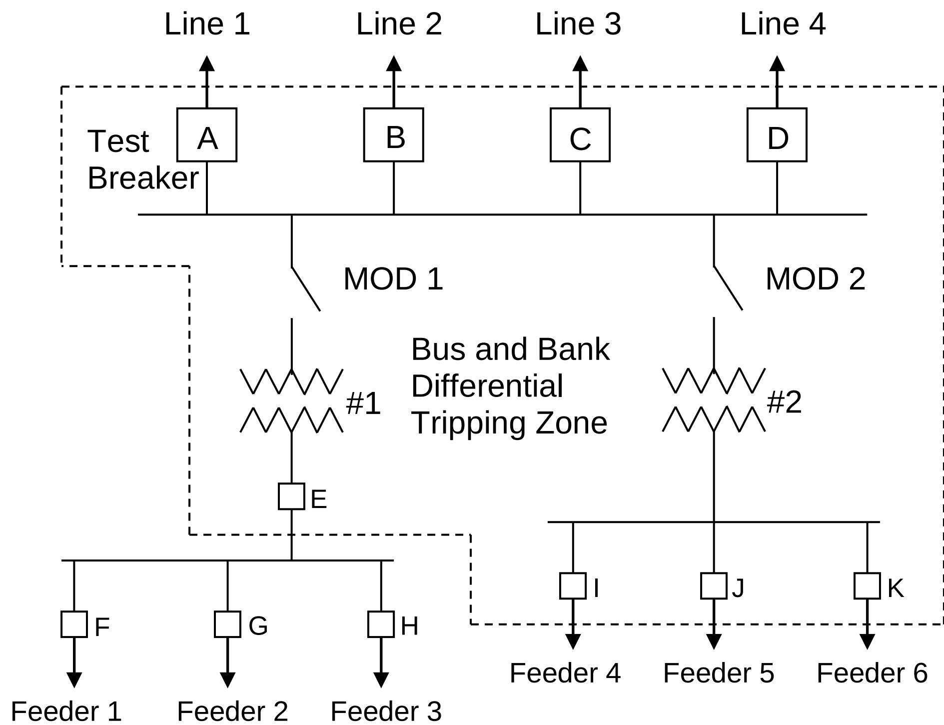

Figure 3 - Typical bus differential tripping zone

Figure 3 above shows the typical bus differential tripping zone. Since the motor operated disconnect switches cannot interrupt fault current the bus testing scheme must trip the first breaker on the low voltage side of the distribution transformer. On transformer #1 this would be breaker E, and on transformer #2 this would be breakers I, J, and K.

History of High Voltage Bus Protection Design

Over the years, the bus protection scheme has gone through several generations of designs. The following sections will discuss each generation design, including advantages and disadvantages of each design.

First Generation Design

The first design in the 1950's utilized telephone relay logic. An automatic box was filled with telephone relays and thermal tube timers to perform the logic necessary for the automatic bus testing scheme. Tripping of the breakers was accomplished by hinged armature auxiliary relays with heavy duty contacts picked up by the electro-mechanical bus differential relays and dropped out by the testing logic when all breakers in the tripping zone were open.

The breaker failure relay in each line panel tripped exactly the same as the differential relays. If the slow breaker came open and the fault was interrupted by the bus being tripped, the failed breaker would be allowed to close, possibly into the same fault.

The automatic testing of distribution transformers connected to the high voltage bus was also controlled by the bus differential logic. If the transformer had a low side breaker, no automatic testing of the transformer would occur after a differential or overcurrent bank protection trip. If the transformer did not have a low side breaker leaving the entire low side bus in the bank differential protection zone, a test of the transformer and low side bus would be made automatically.

The bus differential scheme was flexible enough to handle some variations in the number of transmission breakers and in the configuration of the distribution transformers. Some applications required primary and secondary test breakers, which was difficult to add to the original design.

The design used a low impedance bus differential relay wired for 3, 4, or 6 current inputs. These inputs had to be carefully arranged between loads and sources to avoid mis-operation during external faults, especially when more than 4 devices were connected on the same bus. The bus differential relays had the requirement that all current transformers must be connected with the same ratio, any corrections to current transformer ratio had to be made with auxiliary current transformers. The characteristics of the relay were fixed, the sensitivity could not be changed to match the available fault current.

<u>Advantages to Telephone Relay Design:</u>

1) Telephone relays were inexpensive and readily available, having been used for many years in the communications industry.

2) The relays were small and required little panel space.

3) Relatively complex control schemes could be implemented.

<u>Disadvantages of Telephone Relay Design:</u>

1) The number of contacts on one relay was limited.

2) Any change to the logic required rewiring, which could involve adding new relays and soldering connections between relays.

3) Having a large number of relays that were operated infrequently led to reliability problems.

4) Replacing defective relays was difficult and time consuming. A large number of different spares had to be stocked, such as time delay on pickup, time delay on dropout, and various types of thermal tube timers.

5) By the 1980's telephone relays were becoming harder to find and more expensive to purchase.

6) No self-test monitoring to SCADA available on this design.

Figure 3 - *First Generation Panel* showing the automatic box at top containing the telephone relays, the auxiliary tripping relays and the differential relays at bottom of the panel.

Figure 4 - Close up view of automatic box showing telephone relays.

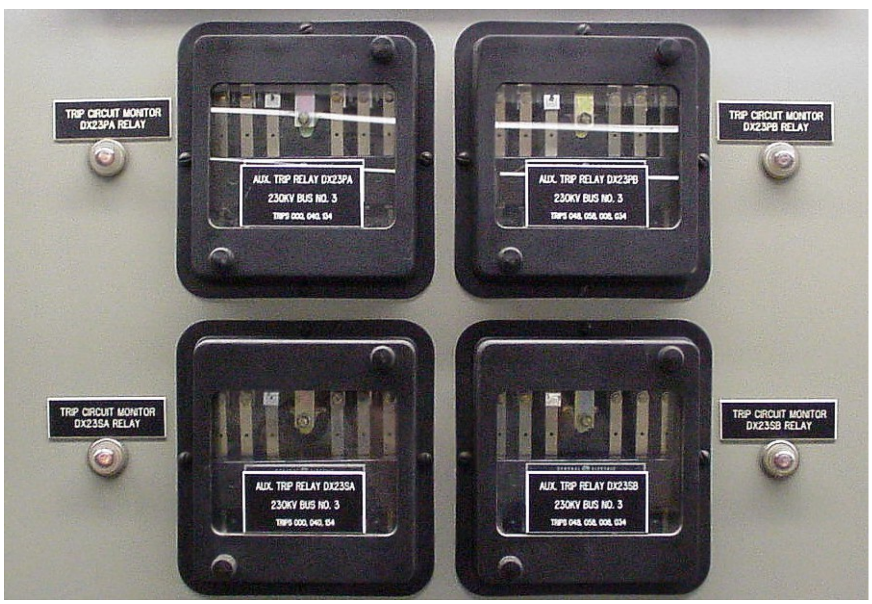

Figure 5 - Close up view of hinged armature auxiliary tripping relays.

Second Generation Design

The second generation was created in the 1980's. This automatic testing scheme utilized an electro-mechanical stepper switch. The switch chosen had eight positions, with a combination of normally closed and normally open contacts on 12 decks. The scheme logic was controlled by the stepper switch with a few external relays. The stepper switch would automatically reset itself if bus testing was successful.

The hinged armature type tripping relays from the first generation design were replaced by rotary action electric reset lockout relays. These provided more output contacts for tripping and close blocking.

Breaker failure tripping was now directed into separate manual reset lockout relays, preventing automatic testing after a breaker failure operation.

Advantages of the Stepper Switch Design:

1. The parts count was reduced which improved reliability.

2. Hard to find telephone relays were eliminated.

3. Soldered connections were eliminated making changes to logic easier to implement.

Disadvantages of the Stepper Switch Design:

1. The flexibility of the scheme was still limited.

2. The stepper switch was mechanically complex, and reliability might be compromised by long periods of inactivity.

3. Like the telephone relay logic, a problem in a scheme component could only be found by testing, because there was no self-test monitoring to SCADA.

Figure 6 - *Second Generation Stepper Switch Panel*

Figure 7 - Close up of stepper switch showing indicator lights for reset (home), in-progress and lockout

Third Generation Design

The third generation automatic testing scheme was placed in service in the early 1990's and utilized a Programmable Logic Controller (PLC) in place of the stepper switch of the second generation design. All control inputs from differential relays, lockout relays, breakers, motor operated switches, and control switches were brought directly into the PLC and all control outputs were brought out of the PLC to tripping auxiliary relays, test breaker close circuit, indicator lights, and SCADA.

The same rotary action electric reset lockout relays were retained, breaker failure tripping was still directed to manually reset lockout relays. In addition, testing philosophy changed to no longer automatically test distribution transformers connected to the transmission bus.

Advantages of the PLC Design:

1. Parts count reduced over the stepper switch design.

2. The PLC performs internal monitoring and is able to send an alarm to SCADA if there is a failure.

3. The internal logic allows virtually unlimited contacts from each logical relay coil, making complex schemes easier to create.

Disadvantages of the PLC Design:

1. The PLC is a computerized device that is subjected to the extreme environment of a substation.

2. The device requires programming before it is installed, creating training issues for the office and field personnel.

3. Software is needed to communicate with the PLC, updates have to be provided to many people in the company.

4. The protection and control functions are connected but not fully integrated.

5. Increased maintenance issues over the years, due to part obsolescence.

6. The differential relays are still electro-mechanical devices lacking in the ability to provide fault recordings and event records to help analyze system events.

Figure 8 - *Third Generation PLC Panel* with PLC mounted in back

Figure 10 - Close up view of programmable logic controller in rear of panel.

Figure 11 - Close up view of auxiliary tripping relays, manual reset breaker failure relay in the middle and the electric reset lockout relays on the outside.

Fourth Generation Design

By 2004 most protection schemes used by Georgia Power Company had been redesigned to use microprocessor relays. When it was decided to redesign the bus differential panel a set of specifications were sent out to interested manufacturers. Several of them submitted relays to be evaluated.

Important features required were:

- The relay had to have internal logic powerful enough to implement the automatic bus testing scheme used by Georgia Power Company. The relay needed to monitor all breakers in the tripping zone, provide outputs to control each motor operated disconnect switch, and indicate the state of the testing scheme.
- The relay had to have a minimum of 8 three-phase current inputs.
- Recording of fault and microprocessor event data was needed.
- Application of mixed CT ratios on the circuits without the use of auxiliary current transformers that would be necessary in a high impedance scheme. Future circuit breakers of any CT ratio could be easily added.

The relay chosen was microprocessor low impedance bus differential relay. Protection and control functions are fully integrated in one box. Up to 8 three-phase current inputs could be brought into one chassis, the control and protection functions are integrated together in the internal logic, and the relay is available with enough inputs and outputs to interface with any size transmission bus used on the system.

The chosen relay provided secure and reliable operation during CT saturation and low fault magnitudes. This was an improvement over existing electro-mechanical relays in the many substations with fault currents exceeding 40,000 amps.

Advantages of the Microprocessor Relay Design:

1. Most of the complex interconnecting wiring of the previous schemes is eliminated.
2. The microprocessor relay can monitor the various inputs to the control and protection schemes, making trouble shooting easier.
3. The microprocessor relay monitors and reports its own health and alerts any failures to SCADA.
4. A modern microprocessor relay provides recording of fault waveforms on each current input and the status of all control inputs and outputs.
5. The microprocessor relays can be accessed remotely, providing information on the state of the protection scheme and to retrieve event & fault data.
6. Standard setting files and logic can be developed and quickly downloaded to relay.

Disadvantages of the Microprocessor Relay Design:

1. Training is required to set and install a new microprocessor relay.
2. New software is needed to communicate with new microprocessor relay.

Figure 12 - *Fourth Generation Microprocessor Relay Panel* with the lockout relays on top (two manual reset for breaker failure and two electric reset for differential tripping), the microprocessor low impedance bus protection relay and the test switches at the bottom.

Implementation of Reclosing / Test Logic within Microprocessor Relay

The following automatic testing scheme was implemented within microprocessor low impedance bus differential relay using the relay's internal programmable logic:

a. Bus differential elements trip all breakers via output to electric reset lockout relay.
b. Autoreclosing is blocked for all breakers.
c. Verify that all breakers have opened.
d. Automatically reset lockout relay.
e. The "test breaker" closes to energize the bus and distribution transformers ("first test").
f. If the fault remains, the test breaker is tripped by bus differential elements. If bus remains energized for five seconds, release reclosing block and conditions restored to normal.
g. If first test has failed, open the motor-operated-disconnect (MOD) switches of the distribution transformers.
h. The "test breaker" closes a second time to energize the bus ("second test"). If bus remains energized for five seconds, release reclosing block on all breakers except those on the low voltage side of the distribution transformers and conditions restored to normal.
i. If test breaker trips again, the station is "locked-out" until scheme is manually reset via external pushbutton.

The below list details the contact inputs and outputs used within the scheme:

Contact Inputs	**Contact Outputs**
52/b Status of Connected Breakers	Trip All Breakers (operate lockout relays)
52b Status of MODs	Close Test Breaker
Lockout Relay Status	Open MOD Switches
External Pushbutton Reset of Scheme	Reset Lockout Relay
	DST (block reclosing on all transmission breakers)
External jumpers to determine if the bus test is "one step" or "two step"	DTst (trip & block reclosing on all breakers on the low voltage side of distribution transformers)

Field Experience

This automatic testing scheme has been in service in substations throughout Georgia Power Company for 15 years now and has successfully restored service many times.

Fifth Generation Design

To maintain multiple suppliers in critical technology Georgia Power added a second vendor of bus differential relays in 2012 capable of performing the automatic bus restoration logic.

The fifth generation high voltage bus protection design now includes primary and secondary microprocessor bus differential relays. Only the primary relay performs the automatic high voltage bus testing logic. The secondary bus differential relay is for backup protection on these critical busses.

Implementation of Reclosing / Test Logic within Microprocessor Relay

The same automatic testing scheme was implemented within the fifth generation microprocessor low impedance bus differential relay as was used in the fourth generation relay using the relay's internal programmable logic:

a. Bus differential elements trip all breakers via output to electric reset lockout relay.
b. Automatic reclosing is blocked for all breakers.
c. Verify that all breakers have opened.
d. Automatically reset lockout relay.
e. The "test breaker" closes to energize the bus and distribution transformers ("first test").
f. If the fault remains, the test breaker is tripped by bus differential elements. If bus remains energized for five seconds, release reclosing block and conditions restored to normal.
g. If first test has failed, open the motor-operated-disconnect (MOD) switches of the distribution transformers.
h. The "test breaker" closes a second time to energize the bus ("second test"). If bus remains energized for five seconds, release reclosing block on all breakers except those on the low voltage side of the distribution transformers and conditions restored to normal.
i. If test breaker trips again, the station is "locked-out" until scheme is manually reset via external pushbutton.

The below list details the contact inputs and outputs used within the scheme:

One design change in the fifth generation microprocessor relay is the "one step" or "two step" scheme setting is now being selected by setting variables in the relay instead of using externally applied jumpers.

Contact Inputs	**Contact Outputs**
52/b Status of Connected Breakers	Trip All Breakers (operate lockout relays)
52b Status of MODs	Close Test Breaker
Lockout Relay Status	Open MOD Switches
External Pushbutton Reset of Scheme	Reset Lockout Relay
	DST (block reclosing on all transmission breakers)
	DTst (trip & block reclosing on all breakers on the low voltage side of distribution transformers)

Historical Results of Automatic High Voltage Bus Testing

After reviewing more than 37,000 operations over 27 years the following results were seen:

Actual Bus Fault Experience:

Total of 65 events occurred.
The bus was restored 32 times – 49% success rate.
The bus locked out or failed to test 33 times.

Bus Fault (Breaker Failure Trip) Experience:

Total of 66 events occurred.
The bus was restored 16 times – 24% success rate.
The bus locked out or failed to test 50 times.

Accidental Bus Trip (Human Error) Experience:

Total of 42 events occurred.
The bus was restored 28 times – 67% success rate.
The bus locked out or failed to test 14 times.

Bus Trip (Relay Problem) Experience:

Total of 30 events occurred.
The bus was restored 17 times – 57% success rate.
The bus locked out or failed to test 13 times.

Bus Trip (Distribution Transformer Fault) Experience:

Total of 95 events occurred.
The bus was restored 53 times – 56% success rate.
The bus locked out or failed to test 42 times.

The overall success rate for high voltage bus restoration is 49%

Conclusions

Faults on high voltage busses are relatively rare. However, the consequences of losing a major transmission bus can be severe.

Experience has shown that automatic testing a high voltage bus after a fault has been successful 49% of the time. There were a number of cases of the automatic testing scheme malfunctioning, preventing a test that likely would have been successful. A few of the successful instances of automatic testing occurred after bus potential transformers had failed, restoring a bus that now had compromised transmission line protection. However, any time an operation occurs on a bus differential, personnel will be immediately dispatched to the station. The lack of voltage from the potential transformers would cause an alarm to be sent in by SCADA as well.

The rate of successful load restoration after a breaker failure operation was 24%. Most of the operations that were successful were due to slow breakers. Many of these breakers worked correctly on the next trip, and each subsequent trip. There seems to be a problem with many breaker mechanisms binding up after long periods of inactivity. Routine operating tests of breakers could help improve reliability. However, this success rate will continue to drop since the newer schemes do not reclose after a breaker failure.

The newer schemes no longer automatically test distribution transformers so restoration after a transformer or low voltage bus fault will no longer occur. This was a decision made by operations to reduce the chances of catastrophic failures of faulted transformers creating collateral damage to substation equipment which increases outage times. Current standards now require high voltage breakers to connect distribution transformers to transmission busses. When these breakers are installed no automatic bus testing is performed since the most likely failures to take out a bus are high voltage side lightning arrestors which are now inside the transformer differential zone. The high voltage bus will now not be tripped for any bank faults, the category with the most events.

The number of misoperations of the automatic testing scheme emphasizes the need for periodic testing and is related to the fact that many of the first generation automatic testing schemes are approaching 70 years of age. These older first, second and third generation automatic testing schemes are being replaced as part of relay modernization projects.

The fourth and fifth generations of automatic testing designs help improve reliability by implementing protection and control in a single device, provide self-test alarms to SCADA, and fault/event data for post-fault analysis. The sequence of event recorder for inputs, internal operations and outputs within the microprocessor relay help technicians troubleshoot issues.

Credits:

Paul Attaway, Senior Protection Engineer, Georgia Power Company (retired), President, Attaway Engineering

Craig Wester, Senior Sales Manager, GE Grid Solutions LLC

Biography:

Steve Gooding was born in Kenansville, North Carolina and was raised in North Carolina and South Carolina. He received a B.S. in Electrical and Computer Engineering from Clemson University in 1980. Steve joined Georgia Power Company in 1980 as a test engineer in Macon, GA. In 1986 he transferred to the Relay Test Lab in Norcross, GA as a Senior Test Engineer responsible for performing cut-in and maintenance duties across the Georgia Integrated Transmission system. In 1990 he transferred to Mississippi Power Company in Gulfport, MS as a relay application engineer in the System Protection department. In 1997 he transferred back to Georgia Power Company in Atlanta, GA as a Senior Engineer in the Protection and Control Engineering department performing relay application and setting duties. In 2006 Steve moved to the Protection & Control Field Services department where he is Supervisor over the Substation Integration & Automation team. Mr. Gooding is a Senior member of IEEE and a Registered Professional Engineer in Mississippi.