LESSONS LEARNED
From A 400kV Busbar Misoperation Using The IEC 61850 Standard

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The implementation of IEC 61850 standard for substation design and commissioning is rapidly becoming the dominant method of defining grid protection schemes throughout the world. The protection logic that involves dc control circuits is executed internally in the intelligent electronic devices (IEDs) and effectively communicated between the IEDs via Generic Object Oriented Substation Events (GOOSE) messages. Any error in the mapping of GOOSE signals will result in undesired operation of the protection schemes.

The main buses in power substations are designed to carry load currents through the individual feeders as well as high amplitude currents during bus fault conditions. Any delay in fault isolation or improper relay operation could result in severe damage to the substation buses and the equipment connected to them. Therefore, proper design and testing of the bus-bar protection scheme is required to ensure safe and reliable operation of the substation. The complex protection schemes such as bus-bar and breaker-failure protection are relatively easy to design using the modern IEC 61850 standard. However, the implementation of these schemes in the real world poses certain unique challenges.

This article discusses the investigation of the tripping of a 400 kV substation due to improper operation of a bus-bar protection scheme. This incident happened when a zone two fault occurred on one of the 400 kV line feeders, immediately triggering a breaker-failure condition. Under a normal trip scenario, the zone two timer will time out and the line IED will issue a trip signal to the line breaker to isolate the fault. The line IED will also then issue a breaker-failure initiate (BFI) signal to bus-bar IEDs through GOOSE messages. The breaker-failure condition is only declared when the line breaker fails to trip within a specified breaker-failure time. However, in this case, the breaker-failure condition was initiated before the zone two timer expired instead of after.

An investigation was carried out to determine the reason for declaring a breaker-failure condition even before zone two tripping of the line IED. Further analysis of the IEC 61850 network and GOOSE configurations led to
the conclusion that the BFI signal was mapped incorrectly. The bus-bar IEDs were configured to receive a BFI signal through GOOSE messaging for a fault pick-up signal instead of a fault-trip signal by protection IEDs. This minor error caused the entire substation to be out of service. This article discusses testing methods that would help prevent this situation.

INTRODUCTION

The protection schemes used in substations are implemented through protective relays from various manufacturers. Legacy systems that use electro-mechanical relays share critical information such as breaker status, interlock signals, etc., through a network of copper wires monitored by some control center. With the advent of IEDs, data sharing between protective relays and control centers has become possible by using Ethernet and fiber optic cables. This has reduced the amount of copper necessary in substations, making them cheaper to produce and maintain. However, the interoperability between different relay manufacturers has become increasingly difficult, as many IED manufacturers have adopted proprietary standards for data representation and interpretation. In 2005, a common standard was first published by a shared effort from IEC 60870-5-101, -103, -104, and Utility Communication Architecture 2.0 (UCA 2.0), and called IEC-61850.

The IEC-61850 standard allowed direct communication between IEDs from multiple vendors in a substation. The IEDs in a substation followed an abstract model for data definition, which could be interpreted by all the compliant manufacturers. A local area network (LAN) switch connected between IEDs passed the data as GOOSE messages. These messages contain essential information such as control signals and acknowledgements. The implementation of the IEC-61850 standard through LAN-based architecture considerably increased the reliability and speed of peer-to-peer communication. Also, a complex protection scheme could be implemented easily through the LAN-based design without increasing the complexity of physical wiring.

A protection scheme is implemented by configuring the IEDs to send or receive GOOSE messages from other substation equipment. Depending upon the complexity of the protection scheme implemented, a GOOSE message could pass through a number of switches until the destination IED is reached. After analyzing the received message, further actions are carried out by the destination IED. A redundant network in LAN design prevents data loss by re-routing the path taken by the messages. Numerous network topologies have been adopted to maintain an un-interrupted data flow from the source IED to the destination IED.

An IED in the substation can send or receive GOOSE messages to or from many different IEDs in the network. The proper mapping of GOOSE messages between IEDs is essential for execution of a protection scheme. The number of signals mapped depends on the number of IEDs and the elements of the protection scheme being implemented in the substation. The IEC 61850 standard ensures that the control functions and message flags seen on the communication network will be the same no matter which manufacturer device is used. However, mapping the IED’s internal logic to the IEC 61850 standard can be tricky, and great attention to detail must be maintained.

THE SYSTEM

A newly constructed 400kV IEC 61850 substation was fully commissioned prior to the work on this article. It consists of six D-configuration systems, referred to as a DIA by the customer, and is provided with a distributed busbar protection scheme as per Figure 1.

A D-configuration system has three circuit breakers with two outgoing circuits; one circuit is for line and the other circuit is for transformer or bus reactor. Both circuits could be lines as well. For circuit breaker maintenance of any line, the load gets transferred automatically from one bus to the other bus. No changeover of the line from one bus to another is required. For any bus-fault conditions or scheduled...
maintenance, all interconnections will be on the healthy bus, and no disturbance will come to the other circuits. Even if both buses become dead, circuits can remain in service through the tie circuit breaker. This is very advantageous in maintaining system stability.

The IEC 61850-based substation automation system (SAS) architecture used in this substation is shown in Figure 2. This architecture is defined in two levels as station level and bay level. A redundant PC-based human-to-machine interface (HMI) is used to control the substation at station level, which supports communication over IEC 61850-8-1 bus as an IEC 61850 client. An IEC 61850-8-1 inter-bay bus provides station-to-bay and bay-to-station exchanges. In this case, an Ethernet LAN is set up with ring configuration to maintain reliability, availability, and interoperability requirements of the system. Redundant gateways are used to exchange the information to remote network control centers using IEC 60870-5-101 protocol.

The bay level system consists of all circuit breakers, current and potential transformers, power transformers, and protective relays. IEDs in the bay level perform all functions including control, monitoring, and protection. The data exchange between bay level and station level happens with fiber optic ring connection according to IEC 61850-8-1 protocol.

Figure 1: 400kV Substation One-Line Diagram

This busbar protection scheme is implemented for Main Bus I and Main Bus II. All bay control units are connected with fiber optic cable to their main busbar relay for transmitting each bay’s load current values, isolator, and breaker statuses. An equivalent single-line diagram of the substation is configured in the busbar main IEDs for proper replication of the substation and for ensuring correct decision making in the protective scheme. In the case of a bus-fault or breaker-failure condition, the main busbar IEDs make the decision to isolate the faulty feeders by sending a trip command to the bay IEDs and, in turn, the bay IEDs trip the respective bay circuit breakers. This data sharing occurs within the busbar protection relay network; these trip signals are also sent as GOOSE messages over the IEC 61850 bus.

IED ENGINEERING AND SYSTEM LEVEL ENGINEERING

The IED engineering process involves configuring the protection functions, interlock logic, metering functions, etc., in each of the IEDs. This process is shown in Figure 3. The IED configuration description (ICD) file is then exported from each IED, into the substation configuration language (SCL) file. The SCL output contains the IED’s capabilities (logical devices, logical nodes). It also reports the control blocks available in the ICD files that are used as inputs in the system-level engineering design. Configuration tools are used to set up the
communication between various devices. The transmission of the data sets is decided by the report control blocks. Also, GOOSE messages are configured in the system-level engineering tool with GOOSE control blocks.

**400kV IEC61850 Substation Engineering and Commissioning**

Ethernet switch configurations are then defined and downloaded into the switches. In this IEC 61850 network, GOOSE messages have priority over other messages, so Ethernet switches are necessary to support the IEEE 802.1P standard for priority tagging. Finally, once the system-level engineering is completed, the SCL file is re-imported back into IEDs, where all the configured GOOSE inputs coming from other IEDs are connected to the correct functions. Once the configuration is downloaded to the individual IEDs, the complete system architecture is defined.

Using the isolator logic, the busbar relay is capable of identifying and isolating respective feeders connected with the faulty bus. Also, this busbar scheme is combined with breaker failure protection. Any protection trip of respective bay protection IEDs will send a trip signal to respective busbar bay IEDs to initiate the breaker failure protection (Figure 4). If the breaker fails to trip, this action will cause a breaker-failure protection trip with BFI initiation and timer timeout. In IEC 61850 substations, a BFI signal may be configured as a GOOSE message from the protection IEDs to the breaker failure protection relays. The busbar IED will trip all feeders connected with the bus of the faulty feeder. Fault selection is processed by the busbar main protection IED with isolator status [1].

**Breaker Failure Operation Logic**

**IEC 61850 Substation: Normal**

During commissioning of the substation, the protection IED’s operation, busbar protection, and all other trip logic were verified to be in proper working order. Later, an additional bay was added to the existing system. All of the protection schemes associated with the new bay were verified as well.

After successful commissioning of the new bay, a feeder was connected to Bus-I. Subsequently, there was a zone two line fault on the newly added 400kV line. Both Main I and Main-II distance protection relays in the substation sensed the fault correctly on zone two and started the zone-two timer. The zone-two trip timer is set for 300 ms. It was observed that the busbar protection relay operated within 200 ms for this fault and tripped the feeders connected with Bus-I and Bus-II, thereby causing the entire 400kV substation to be taken out of service.

After careful physical inspection of the substation and busbar protection relays, it was determined that there was no real bus fault, and the busbar relay had misoperated due to improper breaker-failure protection. The BFI signal was sent to the busbar IEDs through a GOOSE signal. After careful analysis of the IED GOOSE configuration, it was found that the newly added bay had distance-protection GOOSE messages
configured with a start signal for breaker-failure initiation instead of a trip signal. Since the breaker-failure initiation started the function block timer with a start input, its timer operated within 150 ms instead of waiting for the 300 ms zone two timer to expire first. This caused the breaker failure to trip before the zone two timer. Due to this small mistake, both the Main-I and Main-II protection operated, leading to an entire substation blockout. The erroneous logic is shown in Figure 5.

**Figure 5: Breaker Failure Scheme Operation Logic with Improper Configuration**

Figures 6 and 7 show the signal configuration of the GOOSE assignment for the breaker-failure initiation sent to busbar protection IEDs. This signal configuration is defined in the IED level engineering and in the main-line protection IEDs. Figure 6 shows a simulation example of the wrong GOOSE configuration for breaker-failure initiation. In this case, the zone two start signal has been assigned to breaker-failure protection initiation as a GOOSE output. Whenever a zone two fault occurs, the zone two start signal will send a BFI and cause a breaker-failure trip before the zone two timer completes and clears the fault. Figure 7 shows the simulation example of the corrected GOOSE configuration for breaker-failure initiation. In this scenario, if there is a zone two fault, the breaker-failure protection will not send any GOOSE signal to the busbar IEDs from the main protection IEDs to initiate the breaker-failure trip. The IED will send a GOOSE signal to the busbar IEDs only when there is a trip issued by the protection IEDs.

It is necessary to test the IED's protection schemes and GOOSE signals properly before commissioning the IEC 61850 substation or adding additional bays in the existing IEC 61850 substations. It is fairly easy to verify copper wire schemes for breaker-failure protection schemes or other protection schemes when adding additional bays into service in a conventional substation. In the case of IEC 61850 substations, it requires special care. GOOSE-monitoring software can test an IED's GOOSE configurations before putting IEDs and bays into service. Importing the SCL file of the IED under test into the GOOSE monitoring software can assist in verifying the GOOSE signals as required.

**Figure 6: Example of Incorrect IED GOOSE Configuration**

**Figure 7: Example of Correct IED GOOSE Configuration**

**Figure 8: GOOSE Monitoring, No Operation of Protection Function**
Figure 9 provides an example where the GOOSE signal color is red. It indicates that this signal is high and that the protection function has operated; therefore, this GOOSE will register when the distance protection trip goes high. The mapped IEDs that use this GOOSE signal will process and operate accordingly.

With reference to Figure 8 and Figure 9, any GOOSE used in protection schemes can be tested and verified without any risk of misoperation of the relays or unwanted interruption of the substations. The BFI GOOSE signals have been corrected from a start signal to a trip and downloaded to the distance protection IEDs. Since there is no change in data sets, it is not required to update the system-level engineering in the substation level (Figure 3). Necessary validation of signal mapping and GOOSE configuration in line with substation configuration is required in any IEC 61850 substation when adding new bays into the existing substation.

**CONCLUSION**

IEC 61850 substations are increasing in use throughout the world. Necessary testing procedures, such as one of the methods discussed in this article to validate IEC 61850 GOOSE mappings, are required to follow the commissioning of those stations for proper operation. More challenges lie ahead in IEC 61850 substations, especially when adding additional bays into service within existing IEC 61850 substations. As always, additional care is required at the commissioning stage for any substation.

**REFERENCES**


Dhanabal Mani received his Bachelor of Electrical and Electronics Engineering from Bharathiyar University, India, in 2001. He commissioned the first 400kV IEC61850 substation in India in Madhya Pradesh as a Lead Commissioning Engineer of the Substation Automation Group at ABB India Ltd. He has also developed custom relay applications as a R&D engineer at ABB Ltd, Sweden. Dhanabal joined Megger India as an Application Manager in August 2009 and is presently based in Dallas. He has over 13 years of field experience in protective relaying and commissioning, and has published numerous articles and presented at various international conferences on the subject.

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