

# **A Case Study in the Design, Testing and Implementation of a Modern Substation Automation System.**

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# **A Case Study in the Design, Testing and Implementation of a Modern Substation Automation System.**

## **1. Abstract**

This paper describes the design, testing and implementation of a modern substation automation system for a 63kV transmission substation located in the southern interior of British Columbia, Canada. The automation system design makes use of Bay Controllers, which integrate the control, and protection of individual bays into a single Intelligent Electronic Device (IED), a practice that is still very new to the North American electrical industry. These IEDs provide not only control and protection functions, but also fault recording, event recording, equipment monitoring as well as self-diagnostic capabilities. Also employed in the system are redundant DNP3 gateways, replacing the traditional RTU in connecting the switching station to the system control centre. Prior to delivery of the substation automation equipment, extensive factory testing was carried out on the complete system, including testing of line protection relays using a real time digital simulator. This paper examines the architecture and technologies employed in this system, the advantages of extensive factory testing and the experience gained in commissioning such a system.

## **2. Introduction**

In the southern interior of British Columbia, Canada, natural resource company TeckCominco Metals Limited operates one of the worlds largest fully integrated lead and zinc smelters at its Trail operations facility. The electricity, required to operate the facility, is produced at TeckCominco's Waneta hydroelectric generating station located approximately 10 km south of Trail on the Pen d'Orielle River. Four 63 kV transmission lines carry the power from Waneta to Trail, where the lines were terminated at two aging substations, Tadanac and Warfield, which were also interconnected to the regional utilities 63 kV system (Aquila Networks of Canada).

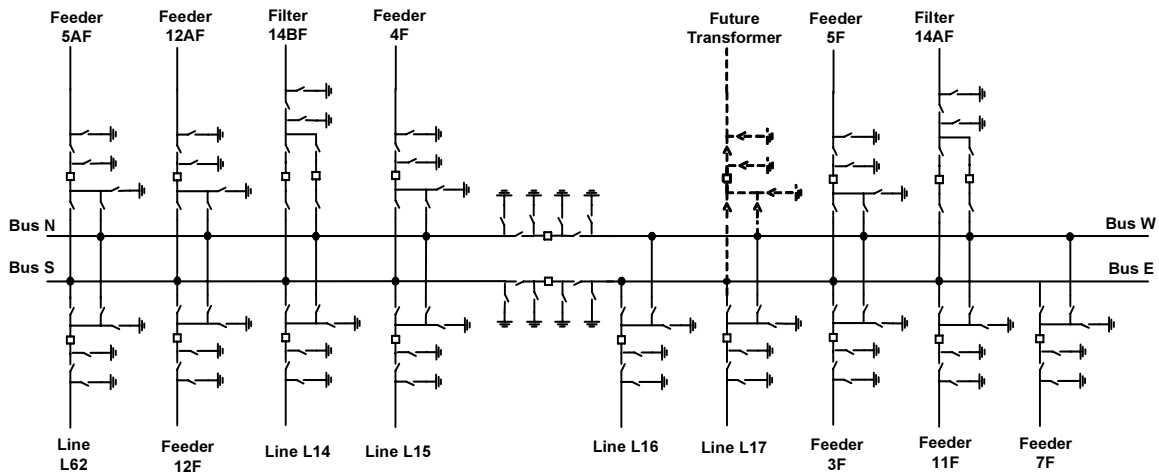
In 2001, TeckCominco began a project to replace the Tadanac and Warfield substations with a single new modern facility. The design of this new facility, named Emerald Switching Station or ESS, was required to have a high degree of reliability in order to securely supply the smelters with power 24 hours a day, seven days a week. However, as the generation, transmission and distribution of power is not central to the core business of TeckCominco, a balance needed to be struck between high reliability and cost.

The advent of microprocessors and networking technology into the realm of substation control and protection systems has, and will continue to have, a considerable impact on the way in which control and protection systems are designed. Multifunction Intelligent Electronic Devices (IEDs), capable of performing a number of complex tasks simultaneously combined with high-speed data networking, enable engineers to dramatically increase the functionality of the traditional substation control, protection and monitoring systems while improving reliability and decreasing costs. Central to the design of the ESS substation automation (SA) system was the use of a type of multifunction IED known as a Bay Controller, which in a single device performs control, protection and monitoring functions. The combination of these historically separate systems into one tightly integrated SA system proved to be an attractive approach to provide TeckCominco with a system that delivered high reliability and functionality at a cost effective price.

This paper provides insight into the design of the SA system developed for ESS including a description of the system architecture, IEDs used, substation networking as well as the station HMI and DNP3 gateways. Key system design features are presented and the benefits derived from these features are discussed. The paper also discusses the extensive factory tests that were performed, which included dynamic protection tests using a real time digital simulator. As well, a description of the on site commissioning performed is provided. Finally conclusions are drawn based on the overall experience of implementing such a system.

### 3. System Design

The new Emerald Switching Station was designed to provide termination for 15 separate elements using single breaker bays to connect the elements to a four-bus ring configuration. The elements included five 63 kV transmission lines, eight distribution feeders and two 35 MVAR filter banks. Provision has also been made in the station for the addition of a future 230/63 kV transformer. The single line diagram for the station is provided in Figure 1 and shows that the station is split into a four bus arrangement with any element capable of being selected onto one of two buses via motor operated disconnect switches.



**Figure 1: Emerald Station Single Line Diagram**

The substation automation system is designed to provide a number of primary high-level functions relative to the overall design of the station. These include:

- Protection functions for the 5 transmission lines, 8 distribution feeders, 2 filter banks and the four station busses in the event of a fault.
- Station interlocking to provide for safe operation of equipment to protect not only the equipment but operating personnel as well.
- Local control of the switching equipment from within the switching station control building.
- Remote control of the switching equipment from the system control center (SCC).
- Local and remote monitoring of measured values, equipment status and other quantities to facilitate network operation.

How these functions, as well as others, are provided by the Emerald SA system is described in the following sections.

#### 3.1. Design Concept

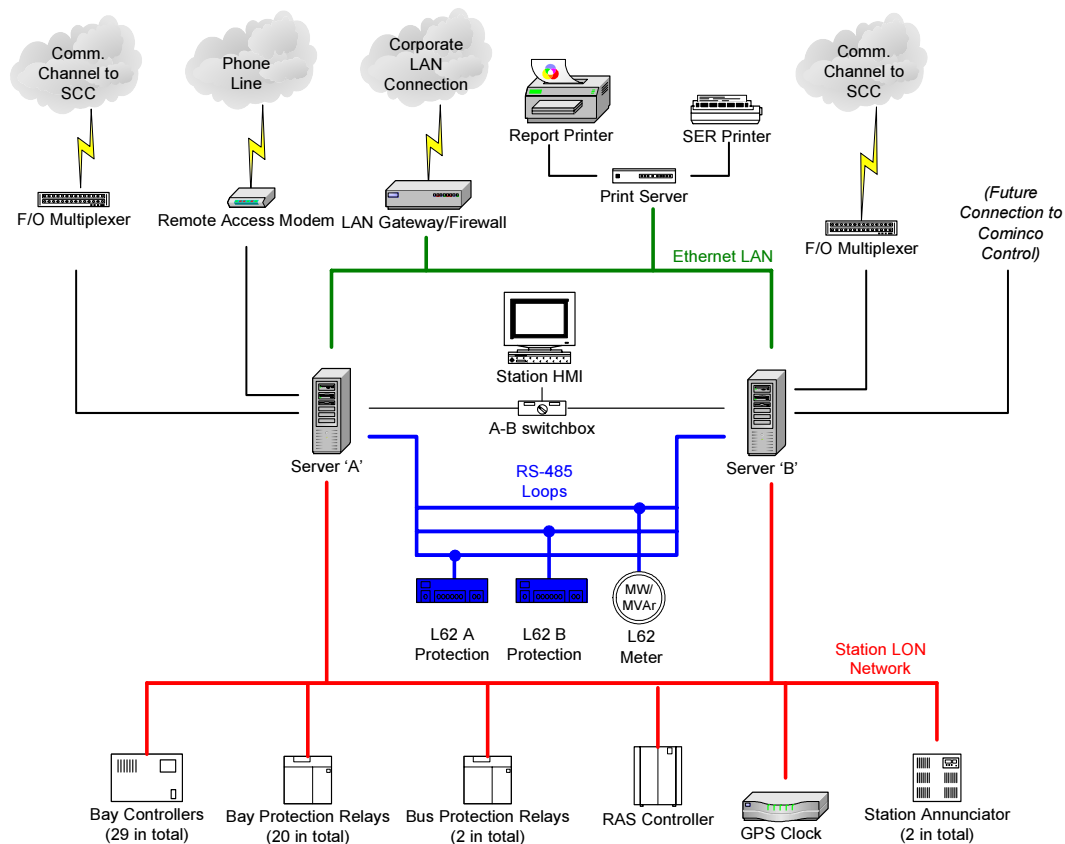
The design of the Emerald SA system is largely based on decentralized control and protection. This concept reduces the need for a centralized station control and places the responsibility for station operation with the IEDs performing the control functions of the bays themselves. In the case of Emerald, multifunction bay controllers were provided in each bay to accomplish this.

The use of decentralized control has a number of benefits including greater reliability because the impact of a single point of failure is localized. As well, because the bay controller

used in this application is capable of also providing protection functions for the feeder bays, the decentralized design results in significant cost savings when compared to a centralized control scheme.

### 3.2. System Architecture

The architecture of the system consists of a number of devices interconnected via three separate networks as shown in Figure 2. The first network consists of a small Ethernet LAN, which interconnects the two station PC servers, a print server servicing the two station printers, and a tie to the utility corporate LAN brought into the station via the fibre optic communications system. This network provides for printing of event listings and trends as well as access to station data from the utility corporate LAN. As this network is not involved in any of the control or protection aspects of station operation, it is deemed non-critical.



**Figure 2: Simplified System Architecture**

The second and main network in the SA system architecture consists of 54 multifunction and conventional IEDs and the two station servers interconnected in a star topology. This LON (Local Operating Network) forms the backbone of the control, protection and monitoring functions and provides both horizontal (IED to IED) and vertical (IED to server) communication.

The third network consists of three small serial RS485 multi drop DNP3 loops used to integrate two relays and a revenue class metering unit into the system that were not able to communicate on the LON network.

Overall, the system was time synchronized to within 1 ms through the use of a satellite GPS receiver which broadcast a time sync signal over the station LON.

### 3.3. IED's Used

In order to provide the required functionality for all of the bays in the station, a total of 58 separate multifunction IEDs are used. The IEDs can be categorized as follows:

**Bay Controllers:** The multifunction bay controllers are the key components in the design of the SA system. While these types of devices are commonly used in European substation automation design, Bay Controllers remain relatively unheard of in the North American power sector. This multi-processor device can have very comprehensive control capabilities combined with simultaneously running multiple protection functions. In the case of the Emerald System, the Bay Controllers are used for feeder protection, all station interlocking, disconnect and breaker operation including synchro check, trip circuit supervision, breaker fail protection, measurement and analysis of analog quantities (harmonic content), processing alarms and events, capturing fault recordings, monitoring equipment condition and self diagnosing problems.

**Protection Relays:** A number of different protection relays are used in the design. These relays perform both primary and backup protection functions for the transmission lines as well as backup protection for the feeder and filter bays. Separate dedicated relays are also provided for bus protection.

**Meters:** Two separate revenue class meters are installed on a 63 kV tie line with the local utility providing backup for the primary meters located at the remote end of the line.

**Station Annunciators:** In order to integrate a number of station service and auxiliary system alarms into the SA system, two 16 input annunciators are provided to process the status contacts into alarms and time tagged events for the system with appropriate checking to provide security.

**RAS Controller:** The only departure from the decentralized control philosophy is for the central Remedial Action Scheme (RAS) controller, which is responsible for shedding load in a managed fashion in response to adverse transmission system conditions triggered by negative rate of change of frequency as measured at the Emerald bus.

For each of the eight feeder bays and the two bus coupler bays, a bay controller together with a separate overcurrent relay for backup protection is used. The bay controller provides the primary feeder protection.

Each of the five transmission line bays utilizes two separate protection relays together with a bay controller. This was done because the bay controller did not have the desired protection algorithms for performing line differential and distance protection required for the transmission lines.

For the filter bays, because of the larger number of switchgear involved, three bay controllers were used for control and primary protection with a separate overcurrent relay for backup protection. As well, three additional bay controllers were used for primary protection of the three arms of the filter (5<sup>th</sup>, 7<sup>th</sup> and 12<sup>th</sup> harmonics).

Finally, two bus differential relays, each with two protection zones, were used to provide protection to the four station buses in case of a bus fault.

### 3.4. Substation Network

To provide the necessary connectivity between the various components of the SA system, a LONWORKS Local Operating Network (LON) is utilized. This open standard network was selected because the majority of the IEDs utilized in the SA system were embedded with the LONTALK Protocol. This protocol is specifically designed to cater to control networks, as opposed to data networks, and has become a de facto standard in certain industries such as building control and automation.

Speed and performance are the key factors in designing a network for control applications such as this. The LONWORKS network is event driven, meaning that information is transmitted only when a value has changed. In critical times, such as during fault clearing, network traffic will be the highest and collisions may be frequent, as a number of devices all attempt to transmit information which has all changed in a very short period of time.

In order to decrease the number of network collisions and therefore increase performance, the LON was separated into 3 subnetworks as shown in Figure 3. Each of these subnetworks utilized starcouplers to facilitate communications between up to 30 nodes per coupler. As well, two starcouplers were equipped with a router card to allow for peer-to-peer communication between the subnetworks. The allocation of IEDs to specific subnetworks was carefully planned based on the following criteria:

- The impact of the loss of a starcoupler was to be minimized by ensuring that IEDs associated with the same bay in the substation were to be allocated to different star couplers.
- In order to keep the performance as high as possible, inter-subnetwork communication was to be kept to a minimum. Therefore, backup protection relays, which required very little inter-subnetwork communication, were placed on a common subnetwork.

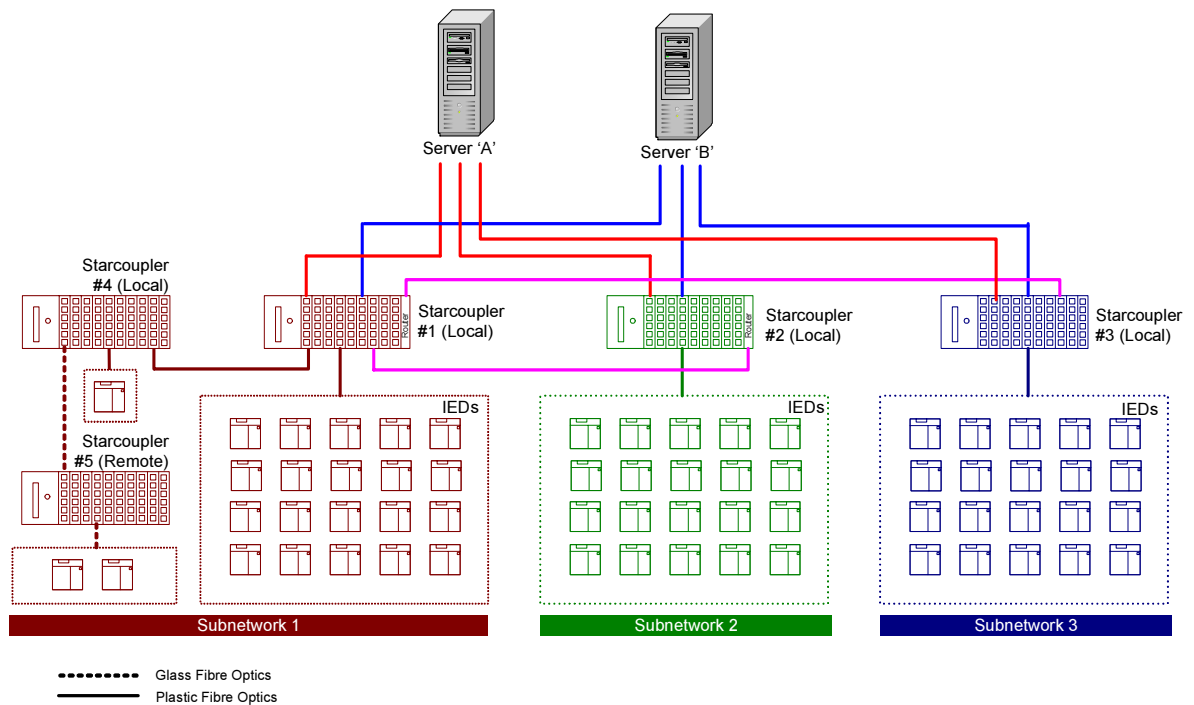


Figure 3: LON Network Details

To improve the reliability of the network, each starcoupler was equipped with redundant power supplies, each fed from a separate station battery system.

Besides the various IEDs connected to the starcouplers, the two PC based servers were each equipped with three LON interface cards to allow both of the servers to communicate directly to all three subnetworks without channelling communication through the router cards. By doing this, the vertical communication performance between the servers and the IEDs was greatly improved.

Due to the close proximity of most nodes in the system, the physical media for most of the network was plastic fibre optics cables. The use of plastic fibre optics made for faster and more economical field installation compared with the use of glass-based fibre optics.

As previously noted, the LON network is event driven. While minimizing network traffic, event driven networks pose certain problems in terms of detecting loss of communication as lack of data transmission is always assumed to be due to a lack of change in information. In order to determine the health of the IED communications, two check algorithms were developed.

The first algorithm was implemented within the programming of those IEDs that communicated peer-to-peer or what is also known as horizontal communication. This data is packaged into 8 bit blocks by the originating IED and 'published' to the network where it is read by those IEDs that 'subscribe' to that information. Since these blocks are only published when one of the bits change state, an eighth bit was reserved for a toggling input that changed state every 5 seconds. This forced the block to be transmitted at regular intervals. All subscribers of this block of data were programmed with timers that would reset when the eighth bit in the block changed state. If this timer reached 15 seconds (which corresponds to three consecutive failed data transmissions), the communication would be considered to be defective. Since the majority of this data was used for interlocking purposes, the receiving IED was programmed to assume the worst case in terms of determining if interlocking requirements had been fulfilled. This would protect against any potentially unsafe switching until such time that the communication was restored.

The second algorithm was used to confirm the vertical communication and was performed by software in the station servers. These servers would conduct a simple poll of each IED in the station once every 30 seconds. Should the server not obtain a response within 2 successive polls, an alarm is generated indicating the failure.

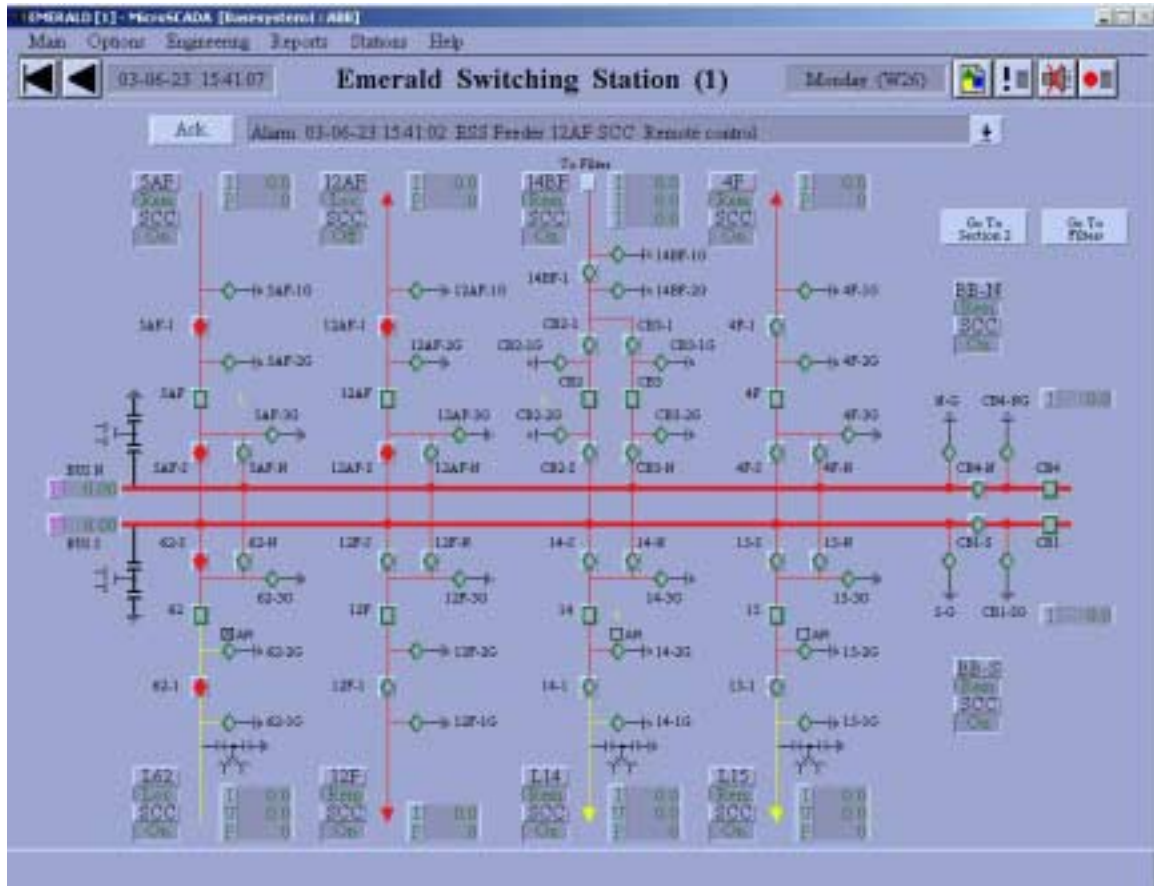
### 3.5. HMI

Human machine interface or HMI functionality is provided by the two PC based station servers connected to the station LON bus and the RS485 DNP3 loops which together, provide direct communication to all IEDs in the station as shown in Figure 2. These servers, running virtually identical SCADA applications, each maintain their own up-to-date representation of the present status of the station as well as a database of historical events, alarms and values. The operator interface to these servers consists of a monitor, keyboard and mouse, which is transferable between the two servers using a KVM switch. As only one server may have the operator interface connected to it at a time, limiting operator commands to be issued to only one server at a time, the two servers are both run in active control mode in a hot – hot configuration.

The HMI provides the following functionality to the operator:

**Single Line Displays:** Three separate single line screens are provided by the HMI for control and monitoring of all primary equipment at ESS. This includes status indication of all switching devices, display of measured analog quantities, select and execute operation of all controllable switching devices in the station as well as animated bus

representation indicating energized and grounded sections of bus. The single line displays also provided the operator with indication of the most recent alarm received by the HMI. One of the single line displays is shown in Figure 4.



**Figure 4: HMI Single Line Display**

**Events Screen:** All events received by the servers are stored in a database and displayed on the events screen. These events can be sorted and filtered in a number of different ways to facilitate quick analysis of incidents.

**Alarms Screen:** An alarms screen provides operators with a listing of the alarms, both active and fleeting, that have been received by the servers. As with the events, the alarms can be sorted and filtered in a number of different ways. A provision is also made for blocking nuisance alarms from filling up the system.

**System Status Screen:** This screen indicates the health of the communication to each of the IED from the server. Should an IED fail a vertical communication check, as described in Section 3.4, the system status screen would provide an indication that the communication to that particular IED has failed.

**Relay Programming:** This screen provides the operator with the ability to select any of the IEDs within the station. Once selected, the HMI will automatically launch the appropriate programming tool for that IED and establish a connection to the IED through the network to facilitate programming and setting changes.

**Configurable Trends and Reports:** A number of trends and reports can be created based on any of the analog values measured by the SA system.

**Fault Recording Collection and Viewing:** Most of the IEDs in the station are equipped with fault recording capabilities. Software applications are provided by the station HMI to automatically upload the fault recording files (in Comtrade format) for viewing and analysis.

### 3.6. Gateways

Traditionally, the role of providing remote control and monitoring of the substation has been fulfilled by a dedicated Remote Terminal Unit (RTU), which was, in many cases, hard wired to the field equipment in parallel to the existing local control and protection systems. Today, via the use of the substation network, the RTU functionality can be accomplished by utilizing a networked device to collect and process the required information directly from the IEDs which are connected to the field equipment.

At ESS, this was accomplished by using the two station servers, which provided the local station HMI functionality, to also act as gateways to the System Control Center (SCC) for remote operation and monitoring. An RS232 port, from each of the servers, is connected serially to SCC at 9600 baud over a fibre optic multiplexed communication system. The servers are set up as DNP3 slaves and report back to the SCC master in response to DNP3 event poll requests (changed data) sent at 1-second intervals and integrity poll requests (all data) sent at 1 minute intervals. Both servers/gateways are running in a hot-hot configuration with either one accepting commands from SCC and acting upon them. The selection of which server is in control is done by an automatic transfer scheme at SCC which will detect lack of response from a gateway and fail over to the other server. It is also possible for the operator to block remote control of the station from the control center on a bay-by-bay basis from the HMI.

In order to limit the bandwidth burden on the communication system, the servers also performed alarm grouping at ESS, which reduced the approximately 2500 discrete points of data into just under 800.

## 4. System Features and Benefits

The ESS substation automation system provides for the main high-level functions of:

- Protection of all elements including the station buswork
- Operational and maintenance interlocking of all switchgear.
- Local and remote control of all station breakers and disconnects.
- Local and remote monitoring of equipment status and measured values and other quantities to facilitate network operation

By using multifunction Bay Controller IEDs, a number of other beneficial functions were provided at minimal incremental cost. Most of these functions aid in increasing in the overall reliability of the station. These functions include:

- Monitoring of circuit breaker tripping duty (I<sup>2</sup>T algorithm).
- Trip circuit supervision.
- Disturbance recordings in most IEDs.
- Autoreclosing possible on line bays.
- Harmonic analysis up to 13<sup>th</sup> harmonic on filter feeders.
- MWh measurements
- Synchrocheck closing on transmission line bays.

- LAN interconnection to the utility enterprise systems allows for fast transfer of large amount of operational data.
- System supervision of IEDs and communication (both horizontal and vertical communication) and failsafe operation in case of communication failure.

The functionality of these IEDs together with the use of networked communication provides a number of quantitative as well as qualitative benefits, especially when compared against a more traditional approach of providing separate control, protection and metering subsystems without networked communication. These benefits include:

- **Reduced equipment costs:** When compared against providing completely separate control, protection, metering and fault recording systems, the designed system cost is less.
- **Reduced engineering costs:** The use of networks to facilitate the flow of information from the field into the upper levels of the control system allowed for decreasing the costs associated with engineering the traditional hardwired method of transferring this information.
- **Reduced installation costs:** As all interlocking was performed in logic within the various bay controllers, the large cost associated with hardwiring interlocking schemes was saved. As well, the use of a simple fibre optic network to facilitate information exchange results in decreased installation costs when compared to the traditional copper hard wired approach.
- **Reduction in O&M costs:** The use of highly reliable IEDs together with the inherent diagnostic capabilities will greatly reduce the maintenance requirements for the SA system. As well, the use of equipment monitoring algorithms within the IEDs will also result in reduced costs if used in an effective reliability centered maintenance (RCM) program.
- **Increased reliability:** Due to the use of highly reliable components, increased monitoring of the substation, detailed diagnostic functions within the SA system as well as the collection of large amounts of data such as fault recordings and breaker wear, the reliability of the SA system as well as the overall reliability of the switching station is improved.
- **Future additions simpler:** By using a decentralized control structure together with networked communication, additions of future bays into the SA system will be easier and will have minimal impact on the operation of the existing system when modifications are made.

## 5. Factory Testing

### 5.1. Dynamic Protection Testing

The four 63 kV lines that link the Waneta G.S. to the Emerald Switching Station are a key interconnection in the area electrical system, delivering power not only to TeckCominco's Trail Operations, but to utility customers in the surrounding area. These four lines also have some unique characteristics which provide some interesting challenges to the protection engineer trying to protect the lines. The first characteristic is the fact that the four lines run parallel to each other on the same narrow right of way. As a consequence of this arrangement, strong zero sequence mutual coupling exists between the lines. This zero sequence mutual coupling has a significant effect on the phase-ground elements of the distance protection, which can result in under-reach or over-reach depending on the line configurations and on the direction of currents in the lines. Another interesting characteristic of the heavily loaded lines is that for many fault conditions, the load current is equal in magnitude, and some times greater, than the fault current itself. This again poses problems with the reach of the distance protection elements for close in and line end faults. Finally, the wood pole construction of the lines built on high resistivity soil lends itself to high fault

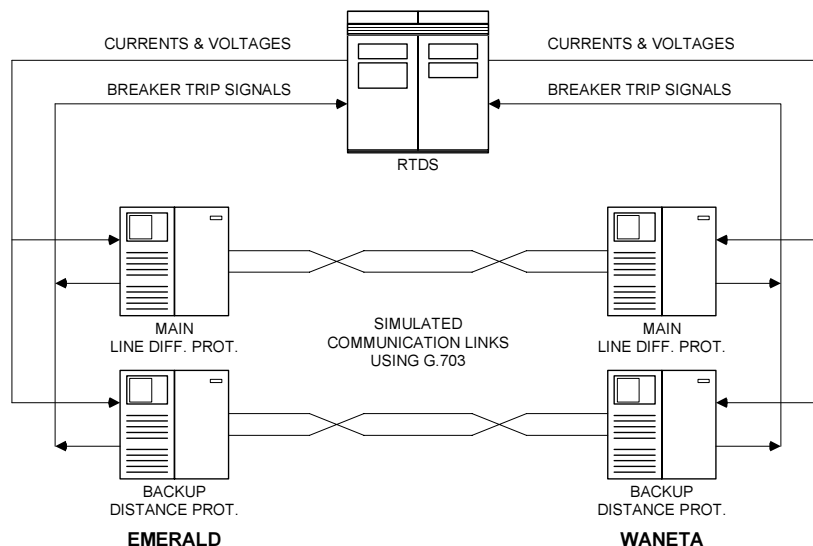
impedances for phase-ground faults. The resistive reach of the distance protection had to be carefully managed to provide maximum coverage while not encroaching on the load characteristics.

Because of the importance of these four lines and the complex characteristics that they exhibit, it was decided to conduct dynamic tests on the protection system to ensure that they would operate securely and reliably under various network configurations and fault conditions.

As part of the Emerald Switching Station project, new numerical line protection relays were installed at the Emerald line ends. Upgrading of the distance protection relays at the Waneta line end was not scheduled to take place until a number of years down the road. The ultimate protection scheme is designed with the main protection consisting of a line differential protection, backed up by communication aided distance protection. As the system was, however, required to operate for the first few years with just the distance protection, the dynamic protection tests were focussed primarily on testing this function.

The dynamic protection tests were carried out using a Real Time Digital Simulator (RTDS). The RTDS is a fully digital electromagnetic transient power system simulator that solves power system equations fast enough to continuously produce output conditions that realistically represent conditions in the real network. The power system model used in the RTDS was obtained from the local utility. This model was equivalized down to a more manageable size and entered into the RTDS simulation software. Included in this overall model were detailed models of the four 63 kV transmission lines which accurately represented the mutual coupling between the lines.

The RTDS was interconnected with the line protection relays to form a closed-loop test system as shown in Figure 5. The simulation outputs from the RTDS (standard secondary level voltages and currents) were connected as inputs to the relays and the trip signals generated by the relays were fed back into the simulator, providing for a realistic testing environment for testing the power system, the relays, and the interaction between the two. Direct relay-to-relay communications were also simulated, complete with signal delays, allowing for the testing of communication aided protection schemes.



**Figure 5: Test Setup for Dynamic Protection Testing**

The event and disturbance recorders built into the protection relays were used to record and evaluate the relay responses to the faults simulated.

The dynamic protection tests were conducted over a two-day period and covered numerous fault simulations under various network configurations. The volume of cases run and the number of different contingencies that were able to be considered during the two days of testing could not have been accomplished by any other means than with the RTDS and would definitely not have been allowed to have been conducted on the actual network. The tests confirmed the complexity of the power system and revealed some important information about the behaviour of the system during fault conditions which would otherwise not have been known.

The net result of the dynamic protection testing was a revised set of protection settings that will improve the overall performance of the protection system and a strong confidence that the protection will indeed operate securely and reliably when called upon to do so.

## 5.2. System Functional Testing

The functional testing of the SA system was carried out in the manufacturer's factory to verify the proper design and implementation of the control and protection systems, including the station SCADA, prior to releasing the equipment for shipment to site.

For the functional tests, all of the assembled control and protection panels complete with all of the IEDs, the station SCADA, the LON network and the DNP3 gateway were connected together in the manufacturer's facility exactly as they would ultimately be connected at site. To simulate the HV switchgear, a black box arrangement of relays was constructed and wired in to the control and protection panels to mimic the operation, running times and positions of the switchgear. A relay test set was used to provide three phase voltage and current signals to the IEDs for checks of the metering and protection functions. Finally, a separate PC was brought in to simulate the DNP3 master station at the System Control Centre (SCC), thereby allowing testing of the DNP3 gateways.

The functional testing was carried out over a period of four days and during that time the following tests were carried out for each of the bays:

- **Operational Tests** – The operational tests were carried out to ensure that each controllable device (i.e. circuit breaker or disconnect switch) could be controlled in local control mode from the bay controller IED, in remote control mode from the station SCADA and in remote control mode from the simulated SCC via the DNP3 gateway. The tests also verified that the proper indication was shown for each device on the bay controller IED mimic, on the station HMI and that the correct status was sent up to the simulate SCC. The test also verified that no valid switchgear position resulted in an alarm being generated.
- **Interlocking Tests** – The interlocking tests were carried out to ensure that each controllable device was unable to be operated under various interlocking conditions. Again these tests were conducted with operation attempted at the local IED level, the station SCADA level and from the simulated SCC.
- **Measurement and Metering** – The measurement and metering tests were carried out to verify that the measured quantities from each bay were correctly and accurately displayed on the station HMI. The IEDs were programmed to send metering data up to the relay when the actual measured value varied outside of a set deadband. Using the relay test set to inject currents and voltages into the IEDs, the magnitudes of the signals were incrementally changed to verify the deadbands and to verify that the correct values were being updated in the station SCADA.

- **Events/Alarms** – All of the alarms and events originate from the IEDs, either as internally generated signals or as hardwired inputs from the field devices. Tests were carried out to check that all of the events and alarms were indicated correctly in the IEDs and that they were addressed correctly in the process database within the station SCADA.
- **System Supervision** – System supervision tests were carried out to check that the loss of communication to an IED resulted in the correct alarm being generated on the station HMI and that the alarm was reset when communication was restored to the IED.
- **Protection Functions** – The protection functions within the relays were tested using the relay test set to verify that the protection functions within the IED's work correctly and that the appropriate events and alarms generated by the protection functions were correctly indicated on the IEDs and on the Station HMI. Due to time allotted for the functional testing, it was not possible to test each individual relay. As a compromise, one of each type of relay was tested.

Overall, the functional testing went very well and provided a number of benefits to the project. The main advantage was the confidence gained in the operation of the system as a whole. If a major problem were to have been found to exist in the system, the best place to resolve the problem would have been right at the manufacturer's facility where all of his resources are available.

The second advantage was that a number of deficiencies were uncovered during the course of the functional tests. The majority of these deficiencies were minor and were able to be rectified and re-tested prior to the end of the functional tests. Identifying and correcting these deficiencies in the factory meant that fewer problems would be uncovered during on-site commissioning, saving both time and money.

Finally, the functional testing was attended by the engineers who would ultimately be responsible for commissioning the system in the field. For these engineers, it was an opportunity to get hands on and become more familiar with the operation of the equipment. This experience not only benefited them down the road during the actual commissioning, but also provided valuable insight during the preparation of the commissioning procedures and scheduling of the commissioning activities.

## 6. System Commissioning

The commissioning of the Emerald Switching Station SA system followed the same basic tests as were conducted in the functional tests performed at the manufacturer's factory, with the main difference being that the system was now connected to real world devices such as the HV apparatus and telecommunications gear.

In commissioning a modern substation automation system it is imperative that the commissioning engineers have an excellent understanding of the inner workings of the substation automation system. The complexity of these systems and the integration of functions within the devices at all levels of the control system differs greatly from the conventional control system of the past which is characterized by the physical independence of functions and exchanges of information via point-to-point electrical links. The commissioning of the modern SA system requires not only the individual functional and performance tests of the individual IEDs, HV apparatus, remote control but also the functional and performance tests of the SA system as a whole.

The first step in the commissioning of the Emerald SA system was to establish communication between the station SCADA and all of the IEDs over the LON network. From this point, the commissioning progressed on a bay-by-bay basis. The field inputs into each IED were verified first at the IED itself and then in the process database running in the station SCADA. Protection

and metering functions were then verified for correct operation and again the signals being sent up to the station SCADA were verified in the process database.

Once the tests on the individual bays had been completed, the commissioning team was at a point whereby the control functions could be tested. It was at this point that all of the field inputs had been verified and all of the interlocking information required by the control functions was now available in the bay control IEDs and across the LON network.

Control of the HV apparatus from the bay level was first verified with valid interlocking conditions. Once the basic control was verified, all conceivable scenarios resulting in invalid interlocking (including communication failures) were tested to ensure that the switchgear could not be operated in an unsafe manner. Once the control was verified at the bay level, operation of the switchgear was then verified from the station HMI and via the communication gateway from SCC. As all of the interlocking logic is based in the bay control IED, the control tests from the higher level systems were only concerned with being able to control the devices and ensuring that the correct statuses were returned following the switching operations.

As was mentioned earlier, a communication gateway using the DNP3 protocol was used in place of the traditional RTU for interconnection of the Emerald Switching Station to SCC. The interesting aspect of the commissioning of the communication gateway was the way in which the status points, alarms and telemetry data were verified through to SCC. As discussed previously, during the commissioning of each bay, all of the data transmitted from the IEDs was verified in the process database in the station SCADA. Once the data was verified in the process database, verifying the data to SCC was simply a matter of manipulating the data in the database to indicate the change of status point, alarm or telemetry value. Verifying the data transmitted to SCC in this manner was extremely efficient and the bulk of the just less than 800 data points were verified in less than two days. Once the SCC addressing in the database was verified in one station SCADA, the database was then copied to the second station SCADA. As the database had already been verified in the first station SCADA, only a random sampling of data points in the second station SCADA were re-checked.

One of the last tests performed on the SA system prior to energization of the station was a network avalanche test. As was mentioned in an earlier section, the LON network was divided into three subnetworks to reduce the number of data collisions and increase the overall performance of the network. It was determined that a bus fault in the station would result in the largest instantaneous demand on the LON network. To simulate this situation, the breakers on one half of the station were all connected to a common bus and a forced trip was issued from one of the bus protection relays to all of the connected breakers. After the test, the sequence of events recorder on both station SCADAs were examined and it was found that all of the data that should have been recorded had in fact been correctly recorded. From the results of this test, it was concluded that the network topology could successfully manage any conceivable loading that it may be faced with.

One final aspect of the commissioning that deserves mentioning is one that has been faced by many designers and commissioning engineers who have worked on substation automation projects. The issue is of course the interfacing of devices from different vendors into a single system. In the Emerald SA system, all but four of the IEDs installed were from a single manufacturer and communicated harmoniously over the LON network. The remaining devices were unable to communicate using the LONTALK protocol and as discussed in an earlier section, were tied into the SA system using a serial RS485 multi drop DNP3 network. The amount of time spent configuring and integrating these devices into the SA system is considerable when compared to integrating the remaining devices on the LON network.

When looking back at the time and effort spent in integrating these four IEDs into the SA system, one can begin to appreciate how the common communication protocol and interoperability of multi-vendor IEDs built to a standard such as IEC 61850 could dramatically improve device

integration and reduce the time and costs associated with the engineering and commissioning of SA systems.

## **7. Conclusions**

The design of the Emerald Switching Station substation automation system successfully utilizes multifunction bay controllers and other IEDs communicating across a substation network to form a tightly integrated system which provides a high degree of functionality and reliability. The decentralized design philosophy distributes the responsibility of overall station operation with the individual bay IEDs thereby removing the need for a centralized control system, which saves on costs. By using multifunction devices, a number of other functions including protection, metering, equipment monitoring and fault recording were available at minimal incremental cost.

Dynamic protection testing in the factory provided an opportunity to evaluate the performance of the system through the use of a Real Time Digital Simulator (RTDS). The tests confirmed the complexity of the power system and revealed some important information about the behaviour of the system during fault conditions, which would otherwise not have been known. The net result was a high degree of confidence and an improved protection system. Functional testing of the assembled SA system in the factory was also performed to verify that key control and protection functions worked as designed. As with the dynamic protection tests, the functional tests provided a high degree of confidence in the system prior to it even leaving the manufacturing facility.

On site, commissioning was done in a stage wise manner starting with individual components, then subsystems and finally the full system. These tests were conducted to re-verify results obtained in the factory tests using the real world devices from the field in place of simulators and test sets.

Overall, the design, testing and implementation of the Emerald Switching Station SA system was very successful. A tightly integrated multi-functional completed system was placed into service, which met all of the design criteria.

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**Max Degerfalt** - Max joined ABB shortly after graduation from University in 1975. Max has more than 25 years of experience in protection system engineering mainly as manager for the system engineering section within ABB Switchgear, responsible for supplying turn key transmission projects on the international market. Since 2001, Max is the Engineering Manager at ABB Inc. Burlington Canada with responsibilities for protection and control system engineering. Max was the ABB lead engineer for the supply of the SA system for the Emerald Switching Station.

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