Design, Implementation and Commissioning of a Remedial Action Scheme

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1 Abstract

In today's increasingly interconnected electrical world, the protection of the electrical network itself is just as important as the protection of the individual elements that make up the network. Remedial Action Schemes (RAS) are designed to monitor and protect electrical systems by automatically performing switching operations in response to adverse network conditions to ensure the integrity of the electrical system and avoid network collapse. This paper examines one such system developed to protect a portion of an electrical network in the southern interior of British Columbia, Canada. The system utilizes a number of different Intelligent Electronic Devices (IEDs) interconnected using a variety of networking and communication systems to form an integrated scheme capable of performing automated shedding of load and generation to avoid collapse of the regional electrical network. The paper outlines the design of this system, beginning with comprehensive system studies performed to examine and determine the requirements of the RAS. The implementation of the system is discussed including the architecture of the system as well as the selection of IEDs used and the role each plays in the overall scheme. Finally, the methods employed to commission the scheme are also provided.

2 Introduction

In the southern interior of British Columbia, Canada, natural resource company TeckCominco Metals Limited (TCML) operates an electrical power system that consists of a load of approximately 220 MW at its smelting operations in Trail, BC and a hydro generating station with a capacity of approximately 400 MW located some 15 km away at Waneta. This system is connected to the Western Grid through interconnections with adjacent utilities. These interconnections comprise 230 kV and 63 kV connections with FortisBC at the Warfield Terminal Station (WTS) and either BC Hydro or BPA at 230 kV at the Waneta Generating Station. The single line for the region is provided in Figure 2-1.

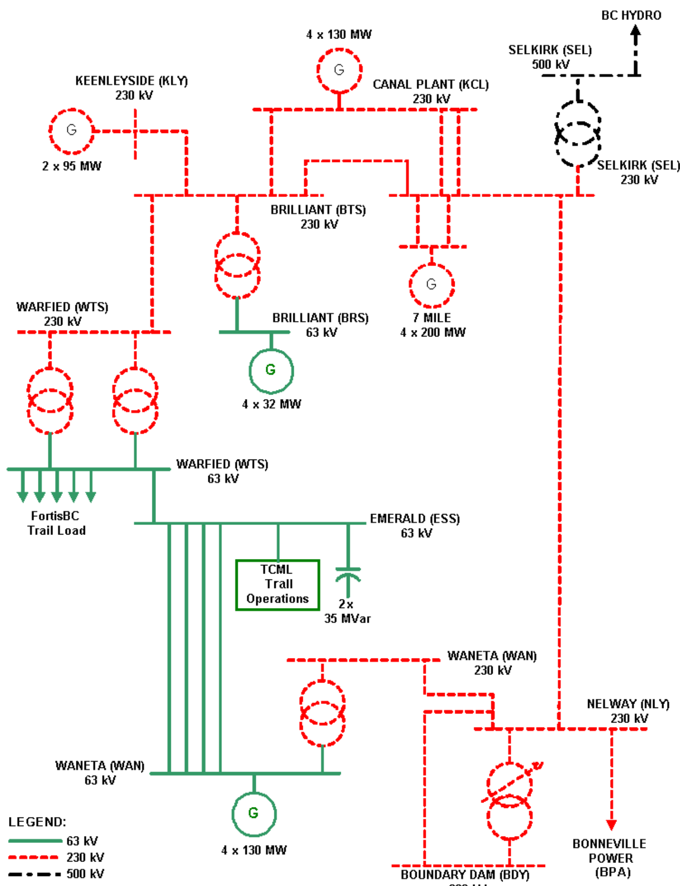

Figure 2-1: Single Line Diagram of Regional Network

The TCML Trail Operations comprises production facilities for the processing of zinc, lead and silver as well as the production of fertilizer. The four rectifiers used in the electro-plating process of the lead and zinc smelting accounts for approximately 120 MW of the total plant load. The remaining 100 MW is comprised of primarily motor loads, the largest being a synchronous motor with a 20 MW rating.

The rectifier loads within the TCML plant can be classified as controllable as they can be disconnected for short periods of time with little impact on the operation as a whole. As these loads are controllable and are typically a constant load, they are ideal for use in a load shedding scheme. The motor loads on the other hand are critical to the operation of the plant processes. It is essential therefore to ensure a secure supply to the TCML plant even under severe network contingency conditions.

During operation of the TCML system, the output of the Waneta generators may either exceed or be deficient to the Trail Operations load. The excess or deficient power is carried on either a 230 kV transmission line through WTS and/or through the 230 kV transmission line out of Waneta to either BC Hydro or BPA.

If, during these periods when the Waneta generator output is not matched to the Trail Operations load, the local 63 kV transmission system becomes islanded from both 230 kV sources, the resulting disturbance may result in significant over or under frequency conditions while the generators attempt to match the load. These frequency excursions could result in an uncontrolled loss of loads or generators and could even result in a complete shut down of the TCML system unless fast action is taken to balance the load and generation.

The remainder of this paper describes the RAS that was developed to limit the deviations in frequency that could occur when the TCML system is islanded due to loss of the interconnections on the 230 kV lines.

3 System Studies

A study of the islanded TCML system was conducted in order to determine the design requirements for a RAS, establish a generator and load shedding strategy, and determine preliminary settings for the scheme.

The criteria adopted for this study was to minimize the magnitude of the frequency excursions within the islanded network, with the following target objectives:

- For surplus load-insufficient capacity conditions, load should be tripped as rapidly as possible to ensure that the remaining connected load is less than the available generation capacity.
- For surplus load-sufficient capacity conditions, governor action alone is not fast enough for most unbalance conditions to limit the frequency decay. Load shedding may be required even though sufficient generator capacity is connected to serve the loads.
- For surplus generation conditions, the frequency rise should be limited by the combination of Waneta generator tripping and governor action, but in no event should it be necessary to trip load, including tripping synchronous motors under out of step conditions.

The initial study was carried out with the PSS/E simulation software using equivalent models of the full WECC (Western Electricity Coordinating Council) system along with a detailed dynamic model of all of the motor loads within the TCML plant. Studies were also carried out using an inertial model of the TCML system.

A range of load flow and stability cases were analyzed to assess the performance of the TCML system under generation surplus and generation deficit conditions, with varying numbers of generators in service at Waneta under varying dispatch conditions.

The results of the study showed that it would be possible to obtain a reasonable estimate of power imbalance in the islanded network based strictly on the rate of change of system frequency (df/dt) and a knowledge of the number of generators that are connected at Waneta. Figure 3-1 shows the correlation between the range of expected rate of change of system frequency and the power imbalance within the Waneta-TCML island. Thus, by measuring of the rate of change of system frequency locally at both the Emerald Switching Station and at the Waneta Generating Station, combined with the knowledge of the number of generators in service, it would be possible to develop independent load shedding and generator shedding schemes.

This concept was adopted as the basis for the design of the RAS system and based on the graph in Figure 3-1, a set of initial protection settings was established.

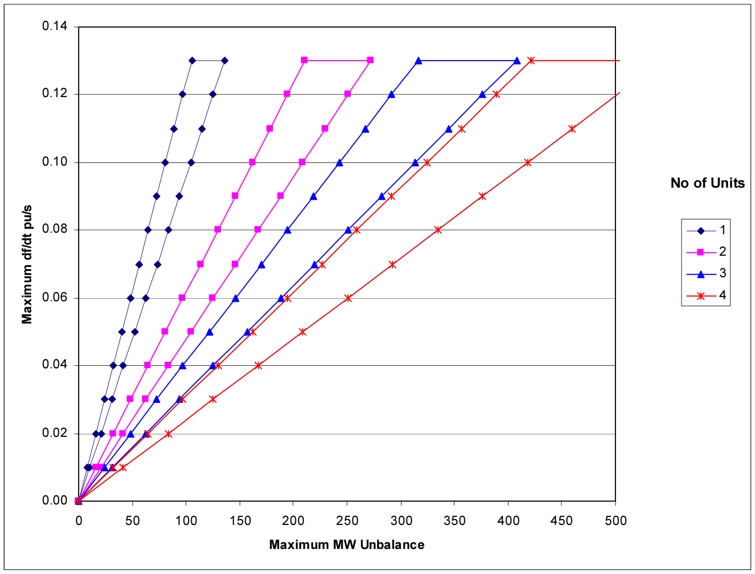

Figure 3-1: Range of Expected Rate of Change of Frequency

The initial studies were based only taking into account the inertia of the generators. Subsequent to the detailed design of the RAS system, a final analysis was conducted with a representation of the generator controls to verify performance of the RAS system as designed and to aid in the determination of the final protection settings.

This final analysis was conducted using the PSLF load flow and dynamic stability programs. The studies considered generation surplus and generation deficit conditions with varying numbers of generators in service at Waneta and varying dispatch conditions. The load and generation shedding actions of the RAS were also modeled in the simulations.

Results indicated that with fewer than three generators on line at Waneta, and with the TCML system importing power, the islanded network frequency collapse would be so rapid that there would be insufficient time for the protection to operate to safeguard the situation. The RAS design was therefore modified so as to immediately shed load when the system becomes islanded and there are fewer than three generators on line at Waneta, regardless of the rate of change of frequency.

The results also verified that with three or more generators on line at Waneta, the RAS limited the magnitude of the island frequency excursions and allowed for rapid recovery to a new steady state frequency. It was also verified that overshoot above 60 Hz after load shedding and undershoot below 60 Hz after generator shedding was minimal and therefore the two operations (generator and load shedding) should not interfere with each other.

4 RAS System Design and Implementation

The design of the overall RAS system incorporates 15 different IEDs, which were integrated together utilizing four different communication networks and systems. A diagram of the complete system architecture is provided in Figure 4.1. As shown in the diagram, the overall system was split into two separate schemes. The load shed scheme was located primarily at the Emerald Switching Station in proximity to the load and the generator shedding scheme was located at the Waneta Generating Station.

4.1 Load Shedding RAS Design

The load-shedding portion of the overall RAS consists of 11 Intelligent Electronic Devices (IEDs) located at TCML's Emerald Switching Station and in-plant Substations 11 and 12 serving the smelter rectifiers as well as two SCADA servers located at Emerald.

The roles of the various components are as follows:

- Central to the scheme is the RAS controller, which is responsible for collecting all data and then, according to predefined logic, taking the necessary corrective load shedding actions as described below.
- Four bay control devices have been programmed to measure and detect specific levels of rate of change of frequency (df/dt). Each of the four bay controllers has been programmed with four separate df/dt setpoints, providing a total of 16 different programmable levels for which load shedding can take place. These devices have also been set up to only detect negative rate of change of frequency, which is the case when load exceeds generation. As well, df/dt detection is inhibited above 59.7 Hz. This allows for minor frequency excursions from 60 Hz without the risk of RAS load shedding operations and also prevents any load shedding from occurring during frequency recovery after generator shedding. As noted in Section 3, undershoot below 60 Hz after generator shedding was minimal.
- Two other bay controllers are located within the plant at substations 11 and 12, which act as terminals to receive, over a fibre optic network, the individual load shedding signals from the main load shed RAS controller and issue the hardwired trips to the associated plant loads. These bay controllers also provided load status information back to the main load shed RAS controller. The extension of the RAS from Emerald into the TCML plant at subs 11 and 12 allowed for the shedding of smaller blocks of load than what was possible by tripping the main supply feeders back at the switching station.
- One bay controller is utilized to provide local status of transmission line L62 that can contribute to the formation of an island.
- Two SCADA servers are provided for display of the RAS status, alarms, operator arming and disarming as well as communication gateways to the main system control center.
- One remote I/O module to provide status signals on the state of the transmission system at the Warfield Terminal Station, which can also result in the formation of an island as well as to send tripping signals to shed load at Warfield if necessary.
- Two line protection relays, which act as communication terminals to the Waneta Generating Station utilizing the G.703 protocol transmitted over a microwave link.

The load shedding RAS controller will operate to shed load within the TCML plant and load supplied by FortisBC from the Warfield Terminal Station, only when the TCML system is islanded from the surrounding transmission networks. Once it has been determined that an island has been formed, based on breaker and disconnect status at Emerald, Warfield, Waneta, Boundary Dam and Nelway stations, the RAS controller is 'armed' to initiate the necessary switching actions as dictated by the programmed logic in response to frequency changes.

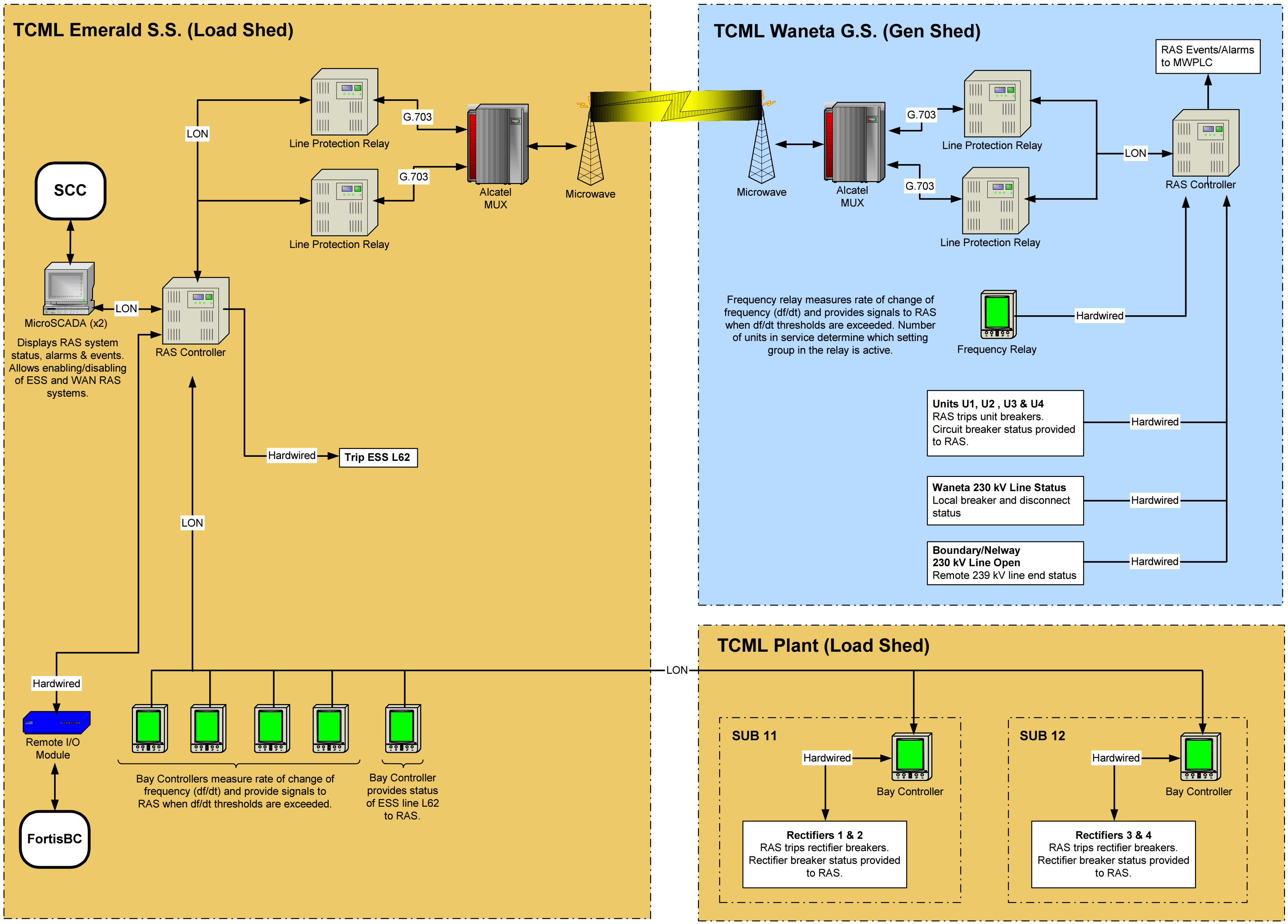

Figure 4-1: TCML RAS System Architecture Diagram

Should there be an excess of load within the island compared to the available generation at Waneta, the system frequency will begin to decline at a rate related to the size of the power imbalance as identified in Figure 3-1. If this rate is sufficient enough to surpass one or more of the set points in any of the four bay controller IEDs tasked with monitoring df/dt, signals will be sent over the Local Operating Network (LON) to the RAS controller. The RAS controller must then determine which blocks of load are to be shed. There are four possibilities:

- TCML Substation 11 Rectifiers No. 1 & 2: 50 MW total
- TCML Substation 12 Rectifiers No. 3 & 4: 50 MW total
- FortisBC WTS Line 34L: 100 MW total
- FortisBC WTS remaining load: 25 MW total

Based on the number of units on line at Waneta, the available connected loads and the magnitude of the rate of change of frequency, the RAS controller will shed the appropriate blocks of load to reduce the frequency deviation and allow the system frequency to return to normal as quickly as possible minimizing the impact of the disturbance.

As noted in Section 3, for those situations where there are fewer than three units on line at Waneta and an island is formed, the RAS controller will not wait for the frequency to decline. Trip signals to shed all four loads are issued immediately to protect the system from collapse.

Besides shedding load, the load shedding scheme is also continuously self-monitoring and provides operators with two levels of alarms in the case of a detected failure. The first level would advise an operator of any problems in the system, but under which, the RAS could still effectively operate. For example loss of one of the redundant microwave communication paths between Emerald and Waneta. The second stage of alarm would advise an operator of any problems detected in the system that would prevent the RAS from functioning.

4.2 Generator Shedding RAS Design

The generator-shedding portion of the RAS system consists of only 4 IEDs all located at TCML's Waneta Generating Station and two SCADA servers located at Emerald Switching Station.

The roles of the various components are as follows:

- Central to the scheme is the RAS controller, which is responsible for collecting all data and then, according to predefined logic, taking the necessary corrective generator shedding actions as described below. The generator shedding RAS controller is hardwired to the generator trip and status circuits as well as having hardwired signals from the disconnects and breakers associated with the 230 kV line to Boundary Dam or Nelway stations. This RAS controller is also hardwired back to PLC inputs used to send critical alarms to the system control center.
- One frequency IED capable of monitoring df/dt and having 4 setting groups, each with 4 adjustable setpoints. This provides for 16 different programmable levels for which generator shedding could be initiated.
- Two line protection relays, which act as communication terminals to the Waneta Generating Station utilizing the G.703 protocol transmitted over a microwave link. G.703 was selected because it was already used to carry line protection signals between the two stations and there was sufficient spare capacity to carry both the existing protection signals and the required RAS signals.
- Two SCADA servers are provided at Emerald for display of the RAS status, alarms, operator arming and disarming as well as communication gateways to the main system

control center. Signal exchange from Waneta back to the SCADA servers at Emerald was done over the G.703 based microwave link.

As with the load shedding RAS, the generator shedding RAS will only operate when the TCML system is islanded from the surrounding transmission networks. Once it has been determined that an island has been formed, based on breaker and disconnect statuses at Emerald, Warfield, Waneta, Boundary Dam and Nelway stations, the RAS controller is ‘armed’ to take any necessary switching actions.

Should there be an excess of generation at Waneta as compared to the connected load at the TCML plant, the system frequency will begin to increase at a rate related to the size of the power imbalance as identified in Figure 3-1. The frequency relay will monitor this df/dt and if the rate of change of frequency is above a set point for two successive 60 ms periods, a hardwired signal will be sent to the generator shedding RAS controller. These two 60 ms delays are programmed in to ensure that the frequency is indeed changing at the detected rate and to allow the generator governor’s a chance to gain control of the situation prior to RAS action.

When the RAS controller receives a high df/dt signal from the frequency relay, the controller decides which generators are to be tripped based on the available units on line, the tripping priority that has been pre-selected by the operators and the extent of the rate of change of frequency. The generator shedding RAS controller will always however, leave the lowest priority unit on line.

5 System Commissioning

Commissioning of the RAS was carried out in an operating electrical system and it was imperative that the commissioning be completed without causing any interruption to the operation of the network. Therefore, the first step in the commissioning of the load shedding and generator shedding schemes was to isolate all of the hardwired trip and signal exchange outputs to the operating network. As well, because of the geographical separation between portions of the system, it was decided to commission the RAS in discrete functional blocks with sufficient overlap between the blocks to ensure nothing was missed.

For the load shedding RAS and generator shedding RAS, the following commissioning tests were carried out locally on each system:

- Verification of df/dt measurement and over/under frequency setpoints
- Verification of signal exchange between local IEDs
- Verification of RAS operating logic within the RAS controller
- Trip tests

Testing of each of the df/dt and over/under frequency setpoints was carried out using a relay test set capable of delivering a linear frequency ramp. After verifying the setpoints, some operational checks were carried out to ensure that the relay did not deliver a trip signal when the rate of change of frequency threshold was exceeded but the over/under frequency threshold had not been exceeded. Additionally, checks were made to ensure that the relays did not operate when the frequency ramp was of opposite polarity (i.e. positive instead of negative df/dt applied to the load shed RAS).

Following verification of the frequency measurement elements, the signal exchange between each of the IEDs of each of the load shedding RAS and generator shedding RAS was carried out. This check included both hardwired signals and those that were exchanged over a LON network.

Verification of the RAS logic for both systems was facilitated by the use of test signals embedded in the RAS logic to simulate the field signals required for correct operation of the RAS. Each of the these test signals could be activated when the RAS controller was put into test mode and could be manipulated from the controller's built in HMI. Use of these test signals allowed for complete testing of the RAS operating logic without having the actual field inputs available.

The final step in the commissioning of each of the load-shedding and generator-shedding RAS systems was "trip testing". Carrying out of these trip tests required coordination with system control operator to first have the element taken out of service and released to the commissioning team for testing. In the case of the generator-tripping scheme at Waneta, the RAS controller tripped the generator breakers through high-speed tripping relays. As these tripping relays had already been proven to trip the generator breakers, the tripping relay outputs were isolated and it was then verified that the RAS controller energized the correct tripping relay.

Following completion of the local commissioning tests, the following external signal exchange tests were conducted:

- Verification of signal exchange between Emerald and Waneta RAS controllers
- Verification of communication from both RAS controllers to SCC

A number of status signals required for operation of the RAS systems are exchanged between the Emerald Switching Station and the Waneta Generating Station. Verification of these signal exchanges was performed end to end between the RAS controllers and again carried out using the test signals embedded in the RAS logic.

The last step in the commissioning process was to verify the communication from the RAS controllers back to the system control centre. These checks included verifying event and alarm data sent by the RAS systems as well as the operator's ability to enable and disable the two RAS systems individually.

Once the commissioning was successfully completed, all of the trip isolation points were removed and the system was turned over to the system control operator for service.

6 Conclusion

The design of the TeckCominco Remedial Action Scheme is based on system studies that determined the design requirements for the RAS, established a generator tripping and load shedding strategy, and determined preliminary settings for the system. In particular the studies showed that:

- It is possible to approximate the amount of MW imbalance in the network by measuring the rate of change of frequency within the islanded transmission system.
- With fewer than three generators on line at Waneta, and with the TCML system importing power, the frequency collapse in the islanded network would be so rapid that there would be insufficient time for the protection to operate to remedy the situation.

Based on these findings, separate load and generator shedding RAS were designed to perform fast switching operations in response to measured rates of change in system frequency when the TeckCominco system is islanded from the surrounding transmission networks. In the case of positive rate of change, generation would be shed at the Waneta Generating Station in proportion to the magnitude of the df/dt. For negative rate of change, load would be shed at either the TCML plant or Warfield Terminal Station in proportion to the magnitude of the df/dt.

The use of rate of change of frequency in determining power imbalance results in a number of benefits when compared to a more standard approach to the problem of summing the total MW generated and subtracting the total MW consumed within the system to determine the imbalance. These benefits include:

- *More accurate response*: The RAS responds more accurately as it is reacting to actual dynamics within the transmission system (df/dt) as opposed to predicted dynamics that may occur in response to a calculated MW imbalance.
- *Faster reaction time*: Monitoring df/dt results in a significant improvement in the reaction time of the RAS. Local df/dt measurements detect problems in the system quicker than summed MW values that must be transmitted between remote sites over the microwave communication system.
- *Reduced communication bandwith*: Communication bandwidth requirements and complexity are reduced when load and generated MW values are not required to be transmitted between stations.

The implementation of the system utilized 15 separate IEDs located at three different locations, integrated together using 4 separate communication networks/systems. By utilizing a method of measuring rate of change of frequency, it was possible to split the load and generator shedding portions of the scheme into two separate systems that could be enabled and disabled independently.

Commissioning of the complete Remedial Action Scheme was carried out with the transmission system in operation. This required careful coordination and preparation to ensure that everyday operation was not adversely affected. Testing was conducted on a functional block basis with sufficient overlap between blocks to ensure nothing was missed.

Ultimately, a tightly integrated remedial action system was placed into service that provides the necessary transmission system protection for the TCML 63 kV transmission system.

Authors:

Ralph D. Kurth, P.Eng. - Ralph was born in Winnipeg, Canada in 1965. He received a BSc degree in Computer Engineering from the University of Manitoba in 1987. Shortly after graduation, he joined Teshmont Consultants of Winnipeg, where he specializes in high voltage ac and dc system commissioning as well as substation control and automation systems. Today he is a Project Manager at Teshmont specializing in substation automation. Ralph was assigned as the Commissioning Manager for the RAS project.

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Dr. R.S. (Bob) Burton, P.Eng. - Bob received his M.Sc. degree in engineering from the University of Saskatchewan in 1970 and his Ph.D. degree from the University of Manitoba in 2004. Bob joined Teshmont in 1970, and has been involved with or responsible for almost all of the power system systems studies that Teshmont has carried out. Bob was responsible for the power system studies and developed the performance requirements for both the under-frequency load shedding and over-frequency generator tripping schemes.

Brent S. Hancock, P.Eng. – Brent graduate from Electrical Engineering in the UK and is a member of the IEE. He has worked in the manufacturing, utility, industrial and consulting business for a period of 50 years. He joined Teshmont in 1986 and is currently engaged in the design and upgrading of the TeckCominco power system. He is a member of CIGRE and IEC TC 17, specializing in power system and switchgear applications.

James N. Roik, P.Eng. - James received his B Sc in Electrical Engineering from the University of Manitoba in 1967. He is a registered Professional Engineer in the Province of British Columbia. James spent much of his career specializing in the fields of Substation Design, Power System Protection and Distribution Design within an electrical utility. He is practicing presently as an independent consulting engineer within the above specialties. James served as a member of the team that designed the protection and the RAS for this project.

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