Idaho Power RAS: A Dynamic Remedial Action Case Study

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Idaho Power RAS: A Dynamic Remedial Action Case Study

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Abstract**—Two separate remedial action scheme (RAS) algorithms reside on a single set of hardware at a transmission substation located in Idaho. The substation is the terminus of three 345 kV, one 230 kV, and one 500 kV transmission circuits. This substation transports power from power plants in the Rocky Mountains to load centers in Oregon, Idaho, and Utah. When one or more of the high-voltage circuits are lost, overloading can occur on the remaining lines across the path.**

The primary function of this RAS is to protect lines against thermal damage, while helping optimize the transfer across critical corridors. The secondary function of the RAS is to dynamically predict power flow scheduling limits on critical transmission lines and corridors.

Idaho Power Company contracted with a supplier to build a state-of-the-art RAS that can trip generation units, bypass series capacitors, insert shunt capacitors at remote substations, or take any combination of these actions. To most effectively determine which level of remediation should occur, a user-configurable set of action tables is used alongside a dynamic arming calculation. A user-configurable nomogram and logic are used for the simpler RAS for lines flowing into Oregon.

I. Background

A. Introduction

As the demands placed on a power system grow, maintaining the stability, reliability, and security of the power system becomes a balancing act for engineers. As consumers, we continually find ourselves embracing more and more power-consuming technology, which increases demand for power and further stresses our installed infrastructure. Owners of electrical power transmission systems constantly juggle the need to build more power plants and transmission lines with how much they cost and when the right time is to invest those costs. Because it is so expensive to build more plants and lines to make our systems more robust, we need to operate the installed infrastructure closer to its operating limits and at higher utilization levels. It is a constant conundrum. Where and when do we spend money to operate systems at their most cost-effective levels?

Another inherent problem of highly stressed power systems is that they will degrade in an unrecoverable cascading fashion when certain significant events occur. The solution to this is millisecond-speed (subcycle) identification and control actions to keep the problems from growing larger, commonly referred to as a remedial action scheme (RAS) or special protection scheme (SPS). Without these schemes in place, permanent damage to electrical and mechanical power system equipment will happen. The more significant the event, the greater the potential damage and, therefore, cost that could be incurred. The revenue dollars lost while system repairs are made further compounds such problems.

A RAS becomes a necessary and cost-effective solution when a power system is not robust enough to accept failures or outages of components without some subsequent response. When a primary protective relay system operates to protect individual components or portions of a power system, a RAS monitors the effect to the larger overall system. If conditions exist that are detrimental to the operation of the larger system or to adjoining systems, then actions are taken by the RAS to remediate the effects. A RAS is the safety control system that monitors and protects a larger power system from additional problems when something within the power system fails.

A fast (subcycle) RAS can double the power transfer capacity across an existing transmission grid [1]. Operating speed, determinism, expandability, processing power to run complex algorithms in milliseconds, and data capture for post-event analysis are key factors that need to be addressed in these schemes.

As shown in Fig. 1, the RAS supports loads served in Idaho and Oregon. Without the RAS in operation, it is generally necessary to lower the operational transfer limit (OTC) of the path when contingencies or operations and maintenance activities remove key lines from service. When demand is high enough and the RAS is in operation, the OTC does not have to be lowered. This allows Idaho Power Company and PacifiCorp to operate path flows (MW) at higher levels throughout the year. Both RAS algorithms meet the Western Electricity Coordinating Council (WECC) requirements, while allowing maximum power transfer across related paths during changes in the system topography.

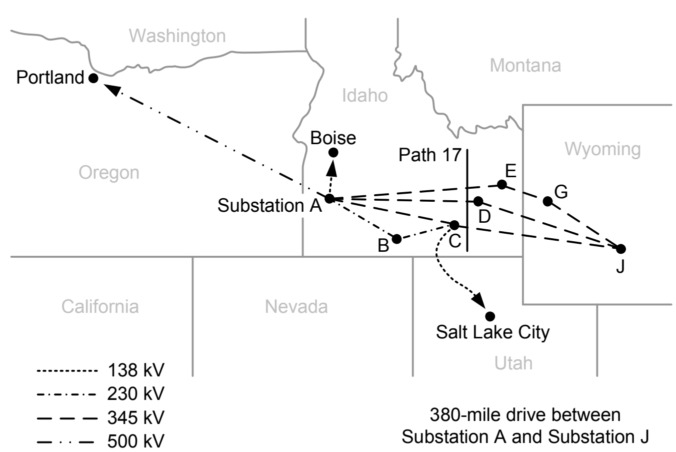

Fig. 1. Geographic area involved

The RAS system described in this paper cost a fraction of what it would have cost to build a new transmission line or to bring a new power plant online, allowing those major costs to be postponed. The RAS allows increased operating revenues during normal maintenance or repair operations and during emergency operations when key system components fail. It also allows Idaho Power Company to be good neighbors with adjoining utilities by preventing problems from propagating out into other systems. With the relatively small investment of the RAS, Idaho Power Company gains more secure and reliable operations, as well as higher utilization levels for key system components, resulting in higher profits and more cost-effective delivery of power to customers.

B. History

The RAS was installed to replace a series of aging and limited systems that worked independently to accomplish a similar, yet much more limited, generation-shedding scheme.

The previous RAS consisted of a collection of discrete contacts, power flow monitoring devices, timers, and tripping relays that had the ability to initiate a very limited response to a small number of conditions. The previous RAS had only two outputs, a Level 1 or Level 2 trip. It could only consider input on conditions from the local substation. It was not adaptive and had to be manually adjusted in order to respond to different system conditions. As such, its functionality and area of influence no longer matched the needs of the system. This initial RAS had to be manually disabled or adjusted whenever related lines were taken out of service for maintenance or repair. During those maintenance or repair activities, the flows across the monitored path had to be drastically reduced to safe operating limits, which translated to reduced revenues. Therefore, a new RAS was needed to meet all operating requirements and to optimize path utilization.

RASs are applied to solve credible single- and multiple-contingency (event) problems. RASs in the Western Electricity Coordinating Council (WECC) supplement ordinary protection and control devices (fault protection, reclosing, automatic voltage regulators, power system stabilizers, governors, automatic generation control, etc.) to prevent violations of the North American Electric Reliability Corporation (NERC) and WECC reliability criteria for Category B and more severe events.

The previous RAS did not meet current WECC design requirements, as outlined in the WECC "Remedial Action Scheme Design Guide" dated November 28, 2006. Also, when a RAS is in place, its operation must be monitored and analyzed to ensure proper response. When a RAS has to be taken out of service, the path flows need to be reduced to safe levels. If a RAS is found to have misoperated, it must be taken out of service and repaired or corrected within the described time frame. Otherwise, the RAS owner could face penalties and fines. These requirements are found in WECC Standard PRC-004-WECC-1 – Protection System and Remedial Action Scheme Misoperation, dated April 16, 2008. The WECC requirements mandate a more complex RAS with high availability, continuous self-monitoring, and the ability to automatically capture data for later analysis.

The new RAS has the ability to monitor much more data and different classes of data inputs from very widely dispersed locations. It can rapidly consider changes to system data and make decisions and effect responses that mitigate further problems, while allowing optimized use of the system. This RAS senses when key system components are removed from service and automatically adjusts its responses as needed. This new system is also redundant, providing very high levels of reliability and availability. It is self-monitoring and captures time-stamped data for analysis and evaluation that are accurate to 1 millisecond. These captured data can be replayed in the original captured form back to the RAS via the playback simulator.

C. Cross Company Boundary Complications

Idaho Power Company owns the RAS equipment that is described in this paper, and is part owner of another RAS installed in Wyoming. The major transmission lines flowing into Oregon are owned by PacifiCorp, but they originate at a substation owned by Idaho Power Company. This cross company ownership of assets makes for a great deal of complication in a RAS. These RASs communicate together over hundreds of miles to form a cohesive control system. Both RASs were designed specifically to protect the interests of both companies.

II. RAS Controller Requirements

A. Timing Requirements

The majority of the system is thermally limited, meaning that upon outages of key resources, overload conditions can occur on other resources. This requires a response time on the order of minutes.

Certain system contingencies for a portion of the system require remediation for voltage stability concerns. This requires a much faster response time. When the typical fault detection, communications time, and unit breaker opening time are excluded from the total time budget, the RAS is left with 20 milliseconds of operating time in which it must operate for certain contingencies. Table I shows the installed RAS throughput time, which meets Idaho Power Company requirements. The RAS total throughput time is the total measured time from an input voltage asserting to 90 percent to an output (trip-rated contact) fully conducting.

Table I
RAS Time Budget

Item	Time (ms)
I/O module input debounce	2
I/O module output contact closure	0.01
RAS controller central processing unit (CPU) processing time	2
Communications transmit and receive signals	<8
Total throughput time	**<12**

B. Reliability Requirements

WECC design guidelines do not require absolute redundancy as long as the failure of nonredundant components does not result in the interconnected transmission system violating its performance requirements. Alternatives to redundant design can also be implemented as long as the resulting response meets system requirements. This is based on an evaluation of the consequences of nonredundant component failure. In most areas, the new RAS implements full redundancy. Some aspects are not redundant, but are monitored and alarm upon failure. All the RAS equipment was designed and hardened to operate and survive in a substation environment.

C. Functional Requirements

WECC monitors a transmission path that lies just east of a key substation. This substation, located in south central Idaho, is the terminus of one 230 kV transmission line and three 345 kV lines coming in from the east that bring power from one of the larger power plants in Wyoming. When one or more of these lines are lost, overloading can occur on remaining lines across the path. This RAS exists to protect against thermal damage to any of these lines, while helping optimize transfer of power across the path.

Much of the power from the power plant in Wyoming is then sent on to Oregon via another path monitored by WECC. This RAS monitors availability of and power flow on the related transmission lines flowing into Oregon. The RAS takes action as needed to maintain voltage stability and protect against thermal damage to underlying circuits in the event that one of those transmission lines open under particular conditions.

Under some circumstances, particularly the loss of the 345 kV lines, the 138 kV line can become overloaded. In order to alleviate overloads on these lines and keep overloads from occurring on surrounding transmission lines, it is preferable to open breakers at remote stations. A transfer trip signal from a thermal overload element programmed in a microprocessor-based multifunction distance relay on the overloaded 138 kV line is sent to the remote breaker that best alleviates the overload condition. This is incorporated into the communications infrastructure of the system.

Three existing RASs were replaced by the new RAS. These RASs performed the following actions:

- Generator dropping scheme for loss of the 345 kV lines.
- Generator dropping scheme for loss of the 500 kV line.
- Line overload RAS for the 138 kV lines.

The first of the three original RASs was initially installed in the 1980s, the last in 1995. Though they have been reliable and have served their purpose, they were very limited in design and were no longer able to meet current and future needs. These RASs were replaced with new, state-of-the-art redundant systems that improve the reliability and maintainability of the transfer paths. This replacement project allows for optimized power transfers across both WECC paths during equipment outages.

The RAS was required to provide a set of fast, reliable, automatic controls to monitor power flow in the system components and monitor ambient air temperatures. The controls are also required to sense changes in the system configuration, determine the optimized response for maximum power transfer and minimum generation tripping, and transmit an output (such as a trip signal to the remote RAS in Wyoming) in less than 20 milliseconds from input detection to output trip initiation (total throughput time). The scheme needed to be reliable and secure with very high levels of availability.

Failure of this scheme to operate correctly could result in damage to the transmission lines, unnecessary tripping of generators, or expansion of disturbances into adjacent systems. Thus redundancy is implemented in this system.

D. Events and Actions

The N events or contingencies that can result in remediation being taken by this RAS are the following:

- The loss of one or more lines from service.
- An overload condition sensed in one of the monitored lines or transformers.

The control actions the RAS can take are the following:

- Add shunt capacitors.
- Bypass series capacitors.
- Shed generation at the power plant.

The RAS was designed to respond to multiple closely timed or simultaneous events; this functionality is key to the optimization of the system with this RAS control strategy.

Table II shows that the RAS logic is all performed at the main substation, whereas digital and metering status information is gathered at six remote substations and control actions are made at eight substations. Many of these substations are hundreds of kilometers from the RAS controller at the main substation. This makes for a system that depends heavily on communication.

TABLE II
SUBSTATION SUMMARY CHART

Substation	Detection	Logic	Action
A	X	X	X
B	X		X
C	X		X
D	X		X
E	X		
F	X		X
G			X
H	X		X
J			X

III. RAS Design

A. System Architecture

Fig. 2 is an overview of the major systems in the RAS. Notice that the right side of this image is a mirror of the left side. This critical equipment duplication creates a system of two completely autonomous control systems; hence the system is considered dual primary redundant. Dual primary redundant schemes have no failover time because both RAS controllers are running at all times. This is in stark contrast to many of the failover or standby redundant schemes employed with outdated programmable logic controllers (PLCs). Dual primary technology is used extensively in transmission protection schemes in North America.

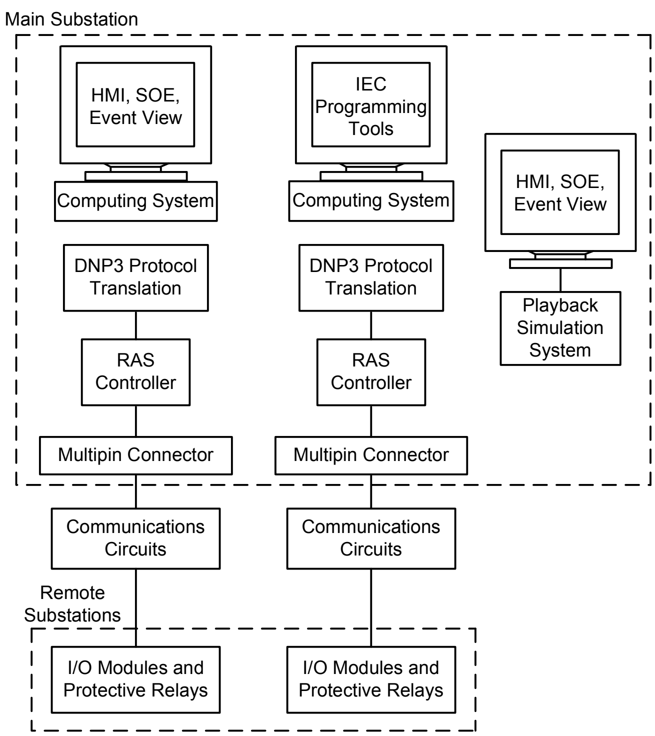

Fig. 2. System architecture overview

Within each RAS system, a single substation-hardened computer provides a user interface (human-machine interface [HMI]), sequence of events (SOE) viewing (SERviewer Software), and event report viewing (oscillography). Another hardened computer is used as an engineering workstation and contains the development environment for all hardware (including the IEC 61131-compliant programming).

Each RAS system (A and B) has its own protocol gateway for communication to the Idaho Power Company energy management system (EMS). These gateways communicate the necessary status, metering, and controls to and from the supervisory control and data acquisition (SCADA) masters via serial DNP3.

RAS Systems A and B are completely isolated on separate networks, and all logic on each system runs without any knowledge of the other system. The decisions taken by the two RAS systems are monitored by a supervision system. If the control actions are identical, both RASs are allowed to operate. If the two RASs come up with different control actions, only the system with the best overall health is allowed to operate.

The router between the two systems is configured to prohibit all traffic between the two RAS systems. The router allows communication from each independent RAS system to the HMI, engineering workstation, and supervision systems.

Not shown in Fig. 2 is a multifunction playback test simulator designed to test the RAS in all system conditions. Modifications or improvements to the RAS can be tested easily by forcing one RAS to test mode and connecting it to a test simulator, while keeping the other RAS online.

B. SCADA Communications

The SCADA gateway systems function as the intermediary for receiving data from the PacifiCorp EMS that will be used in the RAS system calculation algorithms. These gateways are also used for providing data to the EMS regarding the status and operating characteristics of the RAS system.

The RAS can run autonomously from the EMS. This is because all data used by the RAS are provided through independent communications channels.

C. Rugged Design Characteristics

All hardware in the RAS is protective relay-class, substation-hardened equipment with extended temperature range, physical shock resistance, electromagnetic immunity, and static discharge capabilities.

The control algorithm resides on a substation-hardened controller running an embedded real-time controller engine. This engine is programmable in all IEC 61131 programming languages. There are no fans and no spinning hard drives in any equipment. All components run on the substation battery (dc). No ac power is used in the RAS panels.

All outputs used on remote I/O modules are hybrid Form A, trip-rated dry contacts; there are no interposing relays in the system. These outputs are therefore fail-safe (i.e., they remain open unless a tripping scenario has occurred). The hybrid outputs feature submillisecond closing times; this saves approximately 5 milliseconds on the total throughput time of the RAS. These hybrid outputs can also interrupt up to 30 A of inductive current while opening.

Additionally, every zone of the RAS hardware, communications system, firmware, and software contains continuous self-diagnostics. This guarantees the detection of a catastrophic failure of any component in the system. Every device in the RAS design has a normally closed, watchdog alarm contact that asserts if any device is powered down or has a hardware or firmware failure. These contacts are crosswired to other devices for monitoring, which guarantees that a failure in one device will not propagate further.

Communications systems are continuously monitored with protocols that detect the loss of a single serial packet. Additionally, watchdog counters are implemented on all programmable intelligent electronic devices (IEDs), then transmitted to other IEDs, and thus used to detect communications failures.

The logic, settings, and configurations installed on each hardware system are developed and tested to be fault tolerant, meaning that bad computations are intentionally rejected. For example, if a line metered value is out of range or comes from a failed device, an alarm asserts, and the logic declares that specific data as unusable. All logic, settings, and configurations are set up to automatically reject bad data and reselect available (good) data or default to a more conservative value.

A dual Ethernet communications network completely replaces the need for failure-prone, backplane technologies present in most industrial PLCs. The RAS system uses dual redundant Ethernet hardware and redundant communications lines to eliminate all single points of failure in communications between the EMS gateways and RAS controllers.

The result of these design decisions is a RAS that requires two carefully selected, simultaneous hardware failures to prevent RAS operation.

The design considerations for such RASs are nearly identical to those of the industrial power management and control systems regularly deployed by the supplier [2].

IV. RAS Algorithm

To make the RAS fast and deterministic, the RAS logic needs to be efficient. The RAS logic has two parts: data acquisition and RAS algorithm processing.

A. Data Acquisition and Communications Systems

Not all data used within the RAS need to be fast. High-speed data are needed to detect contingencies, whereas low-speed data, such as metering (MW) information, can be used to calculate the RAS actions. This leads to the classification of the required data into two categories: high-speed and low-speed data. This type of data segregation has been proven by the vendor to provide excellent performance on both large and small RASs, industrial load-shedding systems, generation control schemes, and automatic decoupling projects [3] [4] [5] [6].

Between the main substation and all remote substations, there are both high-speed and low-speed data communications streams. Making all the data high speed would require T1 or faster data connections; these were not available or necessary.

Both high-speed and low-speed serial lines are multiplexed together at the remote substation and then transmitted to the RAS over a variety of media, such as devoted fiber optics, leased lines, and microwave. Path diversity was used to reduce the likelihood of simultaneous communications failures to a single location. Statistical multiplexing satisfies the requirement of a fast, deterministic, high-speed data stream and simultaneously passes the large volume of low-speed data over a single low-bandwidth data communications line.

1) High-Speed Data

A proprietary communications protocol was used for high-speed data communications. This protocol is the dominant serial communications protocol used for pilot protection schemes in North America. At 19200 bps, this protocol provides data with deterministic, 4-millisecond updates of digital I/O to the controllers. The protocol itself is built for operational security and therefore is an excellent choice for digital communication for a high-speed RAS. Because of its low-bandwidth usage, it works naturally with bridge multiplexers and microwave equipment. These high-speed data are used to detect N states and will be explained in detail in later sections.

2) Low-Speed Data

Low-speed data are processed every 200 milliseconds by the RAS. These data are used in determining the power system state (J states), determining the appropriate arming levels, and calculating the remedial actions for all the predefined contingencies. These low-speed data include data from the EMS, analog data (such as MW and MVAR), breaker statuses, and out-of-service conditions. Every 200 milliseconds, the RAS decides on the actions that must take place for each contingency, should it occur. These actions are fed into a crosspoint switch (CPS). The high-speed input data are then cross-multiplied with the CPS to issue digital output signals (trips).

B. RAS Logic Processing

The following subsections discuss the major components of the RAS algorithm logic.

1) Data Source Validation and Selection

Digital and analog data selections are accomplished by selecting the data that are deemed the fastest and most reliable, while filling an entire data set with one source. The data selection monitors communications failures with different levels of equipment to select the best data path available. In the RAS, the data are sent through two separate communications processors, as well as the EMS. The RAS operates with a single set of data for all decision-making processes. The single set is determined with this data selection logic. The data validation logic follows the data selection logic and is used to determine whether the analog data selected are valid. This is accomplished by comparing sets of data with those not chosen to ensure that neither is outside of a given threshold from one another. If a single value from two equally healthy data sources exceeds a 5 percent difference, the more conservative (larger) value is used for all generation-shedding calculations.

2) Detect N Events

Any event in the power system that may require a RAS action is identified as an N event (contingency). All of the data required to detect N events must be high-speed data. Two closely timed N events are treated as N-minus-two events, and the RAS is designed to take higher-level actions for these N-minus-two events. The RAS currently has 64 N states. With simple modification, it can be expanded to any number of N states. The following are some of the N states identified in the RAS:

- Substation D to C 345 kV line out
- Substation D to A 345 kV line out
- Substation A to C 345 kV line out

- Substation E to A 345 kV line out
- Substation C to B 230 kV line out
- Substation F to C 138 kV line out

3) J State

Any event that changes the configuration of the power system is identified as a J state. Most N events become J states in the RAS after a fixed amount of time. For example, a loss of a line is an N event. After a period of time, this N event transitions to a line-out-of-service J state. The following are some of the J states identified in the RAS:

- None (system normal)
- Substation E to C #2 345 kV line out
- Substation A to E 345 kV line out
- Substation C to A #1 345 kV line out
- Substation A to C #2 345 kV line out
- Substation C to B 230 kV line out
- Substation F to C 138 kV line out

A J state change does not require a RAS action but changes the configuration of the power system, which forces the RAS system to load a new set of gains into the arming level calculations. Other examples of J states include the outages of synchronous condensers, transformers, shunt capacitors, and transmission lines. J state data do not need to be high speed. The RAS is designed to accommodate 64 J states and, with simple modification, can be expanded to any number of J states.

4) System State

The combination of J states is called a "system state." For example, in an instance when there are two lines open and a capacitor is out of service, these three J states are identified in the system. These three states converge to a system state, and this system state determines the gains used in the calculation of the arming level calculation. In other words, the RAS determines the power system state to categorize every combination of possible scenarios that can exist on the power system.

The RAS uses the system state to determine which gain constants need to be used in the action-determining calculation. A set of user-entered tables selects which system state comes out of each cross-combination of J states. With 64 J states, a total of 64! (64 factorial) system states are possible, but not all system states are valid or possible. Considering future expansions and valid states, a total of 1,000 system states is provided within the system.

The present system state identifies which gain factors need to be used in the arming level calculation equation. These gain factors define the system sensitivity to each component in the arming equation and are developed from system studies.

5) Arming Level Calculation

The dynamic calculation and action tables used for the RAS are a novel way of providing remediation to a power system under stress. These techniques add considerable flexibility and intelligence to the power grid and achieve a RAS throughput time of less than 12 milliseconds.

The arming level equation is basically a polynomial equation that is a function of ambient temperature conditions, local area load and generation, initial loading of the underlying 138 kV and 230 kV lines, compensation level of the 345 kV and 500 kV lines (remote inputs), and seven gain factors that define system sensitivity. The RAS uses the arming level equation and calculates 32 arming levels every 200 milliseconds for each N state identified in the system. These 32 arming levels calculated for an N state are associated with a unique index number that identifies a specific set of actions that need to be taken if that contingency were to occur. The 32 arming levels for each N state are arranged in descending order, and the current path flow is compared to arming levels for each N state. The arming level that is slightly below the current path flow is chosen, and the RAS is armed with the actions associated with the index number of the arming level for that N state.

There are a total of seven matrices that are of the dimensions 64 x 1,000 x 32 x 4. This adds up to a total of 57,344,000 gains, not including several other matrices of smaller sizes. Table III summarizes all the major matrices used in the RAS.

TABLE III
GAIN TABLE ARRAY STRUCTURE

Table	N State	J State	System State	I State
Action index	N/A	N/A	N/A	32
N actions table	64	N/A	N/A	32
N actions reference	N/A	N/A	1000	N/A
Kgins	64	N/A	1000	32
Kloadins	64	N/A	1000	32
Kgenins	64	N/A	1000	32
Kpre138ins	64	N/A	1000	32
Kpre230ins	64	N/A	1000	32
Ktins	64	N/A	1000	32
Kaconstins	64	N/A	1000	32
Two J lookup table	N/A	64, 64	N/A	N/A
PostXX	64	N/A	1000	32
Critical element table	64	N/A	1000	32
Miscellaneous settings	N/A	N/A	N/A	N/A

The RAS also calculates the OTC limit. This limit determines the maximum permissible path flow limit, while not exceeding the permissible overload on the parallel circuits under various overload mitigating actions, line outages, and system configurations.

The path OTC limit for each predetermined outage N and facility out of service J can be expressed by the following equation:

$$\begin{aligned}&\text{BWanj} = \text{Kganj} \bullet \text{JBGen} + \text{Ktanj} \bullet \text{AT} + \text{Kloadanj} \bullet \\ &\text{LALoad} + \text{Kgenanj} \bullet \text{LAGen} + \text{Kprel38anj} \bullet \text{Pre138} + \\ &\text{Kpre230anj} \bullet \text{Pre230} + \text{Kconstanj}\end{aligned} \tag{1}$$

6) Action Table Prioritization

The RAS implemented for the 500 kV line to Portland dynamically calculates 32 action levels that need to be satisfied for each of the preidentified events. These "I actions" consist of combinations of multiple control actions to restrict the system from not exceeding the permissible overload on the parallel circuits. Through the action table technique, the RAS optimizes various overload mitigating actions for all possible line outage and system configuration (system state) combinations.

Using the action table prioritization has many advantages. Its main advantage is to provide a larger number of possible remediating actions out of a handful of actual possible actions. For example, 10 total actions can provide 10! (3,628,800) total possible combinations of actions. This provides more flexible use of various assets, minimizes impact on the system and customers, and prevents over-remediation of events. Because the action table combinations are entered by the user on the HMI, they are easy to understand. Most importantly, this action table lookup technique provides a simple, elegant, and deterministic solution to a complicated problem.

7) Crosspoint Switch

The CPS is the final result of the RAS algorithm. The CPS is a two-dimensional array with indices of N events and actions. The results from the action table selection algorithm are used to populate the CPS. The CPS is loaded dynamically every 200 milliseconds by the RAS. The CPS gives operators information regarding how the RAS will respond for each N event. As soon as an N event is detected, the RAS knows which actions must be taken and triggers the actions. Fig. 3 shows a typical CPS.

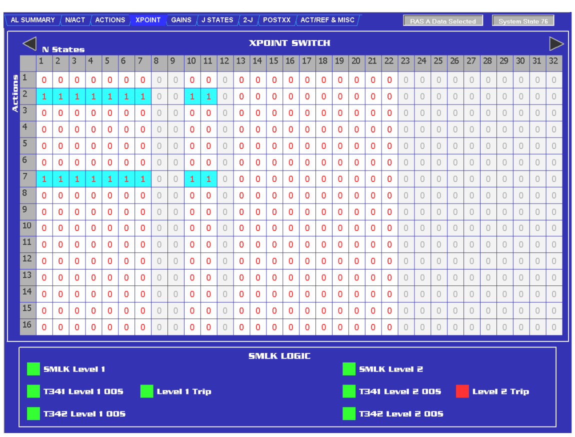

Fig. 3. RAS status screen—CPS tab on RAS HMI

V. Multiple, Closely Timed Events

There are several logic timers used in the RAS logic. Any contingency that happens in the power system creates a disturbance. Consider, for example, a line is tripped. Because of this line loss, the power is redistributed across different paths, or there are power swings causing the gathered analog data to fluctuate as the power system settles toward a steady-state condition. During this time, if the gathered analog data are used in the arming level calculation, it may result in poor-quality decisions.

To prevent these disturbances from affecting RAS decisions for closely timed N events, all values calculated after the first event are frozen for a certain period of time. At the end of the analog freeze timer, the N events are transitioned to J states. If a second event occurs during this time, the timer resets and the process repeats.

VI. RAS HMI

The RAS HMI runs on a substation-grade computer. The HMI is not critical to RAS operation; it is only necessary for changing the settings used for the RAS computations. A complete failure in the HMI will not affect the RAS functionality. All settings inserted by the user at the HMI are stored in nonvolatile memory in the individual RAS controllers.

The RAS HMI station serves as the user interface to all RAS controllers and subsystems. The functionality includes the following:

- Status display of live power system data on a summarized one-line screen.
- Status display for every system input and output, including data shared through the EMS.
- Ability to change and view adjustable settings and gains loaded in the RAS controllers. See Fig. 4 for an example.
- Real-time view of the CPS matrix that shows the action to be taken for every contingency.
- Communications and alarm screens that show the active state of major devices, communications, and diagnostic alarms.
- SOE gathering, archiving, and viewing. All data in the SERviewer Software are time-stamped with 1-millisecond accurate resolution.
- Oscillography event viewing. Event files are saved in a flat file format, similar to COMTRADE format. Equivalent to a digital fault recorder (DFR) in size and sampling rate, these files can be replayed to the RAS from the test simulator. The reports are generated on the controllers and passed to the computers for long-term storage and viewing.

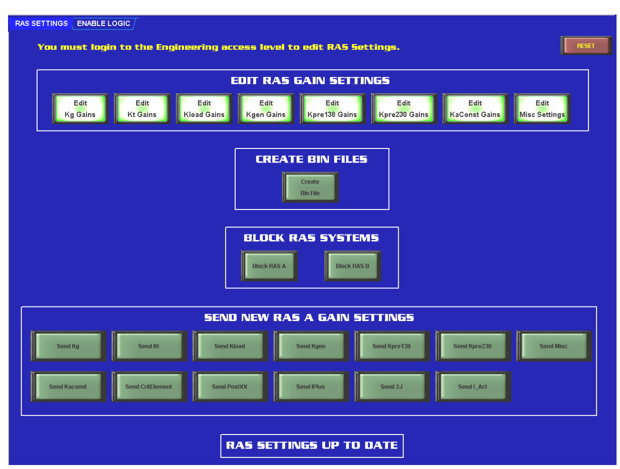

Fig. 4. Sample RAS HMI screen

Database files were created to hold the large number of gain matrices. When edits are made to any one of the gain matrices, the controllers detect that new settings are available and issue a signal that the loaded settings are old. These files are then transferred to the RAS controllers at the request of the operator.

VII. Testing Simulator

The dual primary systems (RAS Systems A and B) are independent of each other. This gives the flexibility to disable either RAS for testing or maintenance and keep at least one RAS available at all times. As shown in Fig. 5, the test simulator communicates to the RAS with serial links, emulating both the EMS DNP3, low-speed, and high-speed serial data streams.

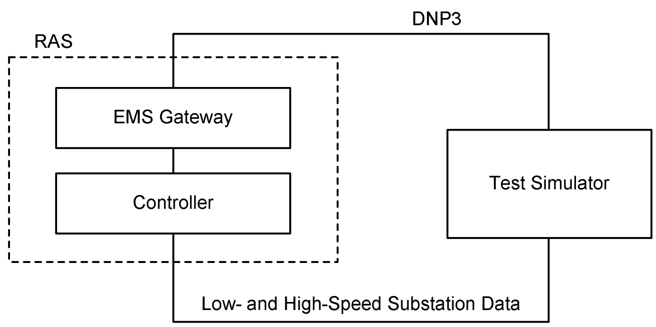

Fig. 5. RAS playback simulator

The test simulator for the RAS simulates all RAS external inputs, including digital statuses, control inputs, analog data, and DNP3 data streams. The test simulator contains an HMI user interface from which an operator can perform all system tests. The test simulator has the following two operating modes:

- Static simulator. This mode provides the operator the ability to drive each individual input to the RAS to a desired value. For example, the system configures EMS set points, set breaker status conditions, and detects generator trips from the RAS. This is extremely useful for testing all I/O points and creating any desired power system scenarios for presentation to the RAS controls.
- Playback simulator. In this mode, the simulator is used to replay one or more event report files to the RAS system. The simulator can play back real RAS system event report recordings of actual events. This was valuable during factory acceptance testing because playback files created by Idaho Power Company could be played back to the system. This is an especially valuable tool for a live RAS because it allows engineers to fine-tune RAS gains for desired operation, with no risk to maintaining power system stability.

Both RAS subsystems are connected to all field I/O through communications lines. For the simulator to actively interact with one of the RASs, large, multipin military-style connectors are used to "unplug" the RAS from live field data and to "plug in" the simulator. When a RAS is connected to the test simulator, the RAS will not receive any inputs or send any outputs to field equipment.

The test simulator has a feature to hold several hundred playback files, which are then queued up for automatic playback, one after another. In this fashion, engineers can observe the reaction of the RAS algorithm to hundreds of different scenarios in only a few hours. This is extremely useful for factory and site acceptance testing.

VIII. Conclusions

The RAS was successfully commissioned in July 2009 and, with outputs disconnected, allowed to run in parallel with the existing RAS over a period of six months. The RAS responses to several events during this monitoring period were analyzed, and the system performed perfectly. Therefore, the RAS went live in November 2009.

The RAS is designed to allow future modifications to occur with little interruption to the performance of the RAS. The hardware design allows for RAS Systems A or B to be disconnected from the live power system and connected to a test simulator. This not only allows for quick changes to occur within the RAS but also for expansion and other maintenance corrections without taking the entire system out of service.

Considering the complexity of the RAS, it was identified that a close working relationship between Idaho Power Company engineers and supplier engineers was crucial. Idaho Power Company engineers spent nearly two months at a supplier site to fully test system performance. Idaho Power Company engineers brought site-specific experience to the factory acceptance testing, proving that all problems on the old RAS were overcome by the new RAS.

IX. References

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X. Biographies

Michael Vaughn is a project manager for Idaho Power Company. Mike has a Bachelor of Science degree in Electrical Engineering from the University of Idaho and is registered as a Professional Engineer in the state of Idaho. Mike has 26 years experience working in the power/systems/facilities engineering realm working for the U.S. Air Force, Power Engineers, the Idaho National Laboratory, and Idaho Power Company.

Robert Schloss is an automation engineer for the Engineering Services Division of Schweitzer Engineering Laboratories, Inc. (SEL). Robert received his Bachelor of Science degree in Electrical Engineering from the University of Idaho and has been with SEL since 2004. He has experience in power system automation, specifically with remedial action schemes, load shedding, and generation control.

Scott Manson is a supervising engineer for the Engineering Services Division of Schweitzer Engineering Laboratories, Inc. (SEL). He received a Masters in Electrical Engineering from the University of Wisconsin–Madison and his Bachelors in Electrical Engineering from Washington State University. Scott worked at 3M Corporation as a control system engineer for six years prior to joining SEL in 2002. Scott has experience in designing and commissioning generation control systems, load- and generation-shedding schemes, special protection schemes, high-speed web line controls, multi-axis motion control systems, and precision CNC machine controls. Scott is a registered professional engineer in Washington, Alaska, North Dakota, and Louisiana.

Sai Raghupathula is an automation engineer for the Engineering Services Division of Schweitzer Engineering Laboratories, Inc. (SEL). He received a Masters degree in Electrical Engineering from the University of Idaho. Sai has been employed with SEL since 2004 and has experience in designing and implementing control systems for utility and industrial customers.

Trent Maier is an automation engineer for the Engineering Services Division of Schweitzer Engineering Laboratories, Inc. (SEL). Trent received his Bachelor of Science degree from Michigan State University and spent five years within the automotive industry prior to joining SEL in 2007. He has experience in control system design and application within power systems, conveyor systems, and robotics.

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