

From Contingency to Confidence: Using a System Integrity Protection Scheme to Address System Overloads and Network Constraints— The Waratah Super Battery Case

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From Contingency to Confidence: Using a System Integrity Protection Scheme to Address System Overloads and Network Constraints—The Waratah Super Battery Case

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Abstract—The Waratah Super Battery System Integrity Protection Scheme is a fully automated wide-area control scheme designed by Transgrid to unlock transmission capacity in New South Wales. The scheme monitors the power flow across 36 transmission lines and communicates with 3 paired generators and a battery to reduce the risk of post-contingent overloading of transmission lines.

I. INTRODUCTION

The rapid transformation of the Australian National Electricity Market—driven by the phase-out of coal-fired generation and the rising reliance on remote renewables—has created significant challenges for maintaining secure transmission operation [1]. With generation shifting to the edges of the network, where renewable resources are abundant but distant from demand, the power system increasingly relies on transmission corridors with a higher risk of thermal overloads. To address these emerging constraints, Transgrid, the transmission network service provider for New South Wales and the Australian Capital Territory, designed, developed and tested a wide-area system integrity protection scheme (SIPS), known as the Waratah Super Battery (WSB) SIPS, within two years, to prepare for the retirement of coal-fired power plants.

Wide-area control schemes have been shown to help unlock additional transmission capacity [2] [3] [4] [5]. Coordinated runback schemes are also used to reduce overloads by curtailing generation in a structured way [6]. The WSB SIPS builds on these approaches by combining sequential runback schemes with the reserved capacity of the WSB to dynamically relieve overloads on critical lines. The SIPS integrates real-time monitoring of 36 transmission lines with centralized decision-making and distributed control of a battery energy storage system (BESS) and participating generators, including a solar farm, wind farm, and hydro plant. It is supported by a fully

redundant communications architecture and a deterministic automation control platform.

Through extensive detailed design, bench testing, and field commissioning, the SIPS enables monitored lines to operate at thermal ratings above normal operating limits, increasing transfer capacity to major load centers, reducing network constraints, and enhancing overall system resilience. This paper presents the system context, design methodology, control architecture, and testing and commissioning process, as well as future expansion of the SIPS.

II. BACKGROUND

Transgrid is the network service provider (hereafter referred to as the service provider) that owns and operates the high-voltage transmission network across New South Wales and the Australian Capital Territory. Its network includes 131 substations, 13,461 km of transmission lines, and 109 km of underground cables. Historically, most of the network generation has been supplied by coal-fired power stations located near the Sydney—Newcastle—Wollongong (SNW) load center. However, in recent years, there has been significant growth in renewable generation in more remote areas of the network.

In February 2022, the early retirement of a 2.8 GW coal-fired power station that supplied approximately 18 percent of the electricity demand of New South Wales was announced [7]. The station was scheduled to close in August 2025, seven years earlier than originally expected. In response, the New South Wales government initiated plans for the WSB, an 850 MW/1,679 MWh (BESS) to be installed near Newcastle. The WSB was planned to have a reserved capacity of 700 MW/1,400 MWh to support the network during transmission contingencies.

A. Legacy Contingency Management Framework

The service provider uses static thermal rating tables to document the ratings of most of its transmission lines. The ratings are divided into normal, contingency, and 5-minute emergency ratings, and vary depending on the season and time of day, as shown in Table I.

TABLE I
LINE RATINGS

Season	Time of day	Normal	Contingency	5-min
Summer	Day	1200	1430	1700
	Night	1290	1520	1980
Autumn/Spring	Day	1250	1480	1820
	Night	1300	1530	1970
Winter	Day	1300	1530	1970
	Night	1340	1580	2090

These ratings are provided to the Australian Energy Market Operator (AEMO) and are included in the constraint equations used by the National Electricity Market Dispatch Engine (NEMDE). These ratings are used to calculate dispatch targets for generators across the National Electricity Market in 5-minute dispatch intervals. The constraint equations are used to reflect the physical limitations in the power system, such as transmission line capacities in the NEMDE.

For a contingency event, transmission lines can operate at contingency ratings for up to 30 minutes before conductor heating causes safety clearance limits to be exceeded. During this time, NEMDE redispatches the system to return the network to a secure operating state. Generators are issued new dispatch targets to unload the network and ensure the lines are operating below their normal rating.

Fig. 1 shows how under the existing NEMDE and rating framework, the transmission network is limited by contingency ratings. If network power flows exceed these ratings, control room operators and NEMDE must work simultaneously to reduce transmission flows. This framework, while secure, places limitations on network utilization and relies heavily on operator intervention. As the grid becomes more dependent on long-distance transfers from remote renewable and storage resources, these strict ratings and redispatch-based mechanisms start to constrain operational flexibility, increase operational costs, and reduce revenue. This growing gap between system needs and existing tools creates an opportunity to develop a fast-acting SIPS that can adaptably manage overloads and support secure operation at higher transfer levels.

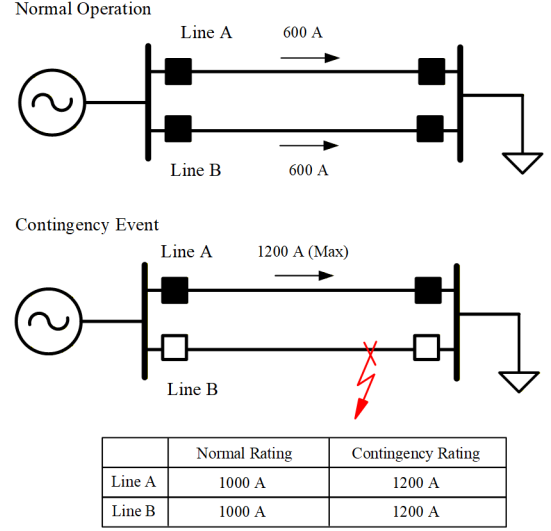


Fig. 1. Normal Operation vs. Contingency Event

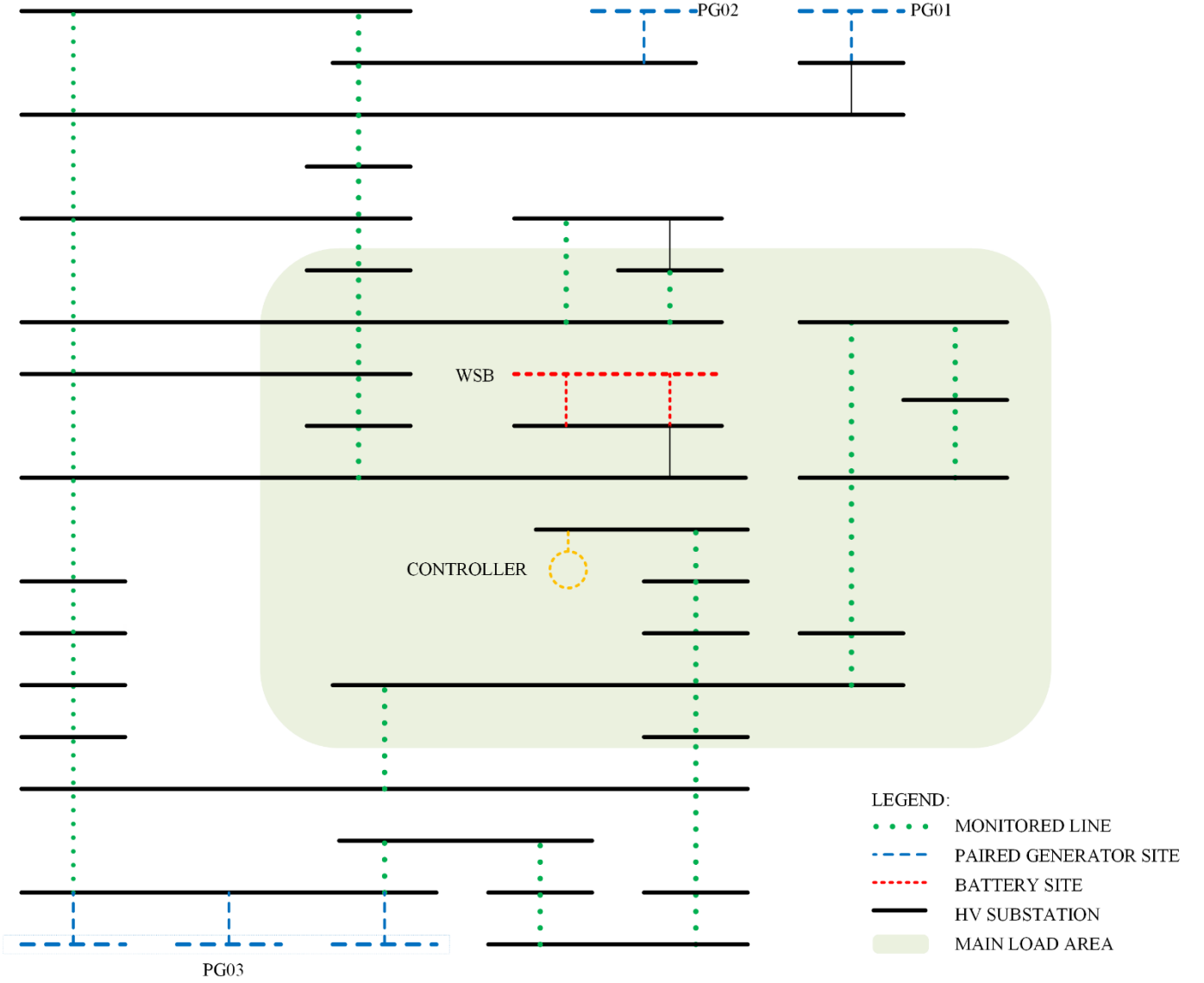


Fig. 2. Simplified One-Line Diagram

B. Unlocking Transmission Capacity With SIPS

The WSB SIPS automates the post-contingency recovery process, reducing the time required to bring the network to normal operational levels. It allows the network to operate at contingency transmission line ratings, unlocking spare thermal capacity of the transmission lines.

WSB SIPS is a wide-area control system that monitors power flows across the 36 transmission lines subject to elevated loading during high power transfers (refer to Fig. 2). If a monitored line exceeds its contingency rating, the system sends runback or generator trip signals (if required) to one or more contracted paired generators while simultaneously increasing output from the BESS. Since the paired generators are located further from the SNW load center and the BESS is located closer to demand, the overload can be relieved while

maintaining supply to the load center. The scheme coordinates these actions and brings power flow of the lines to below seasonal normal ratings within 5 minutes. Therefore, SIPS can allow monitored lines to be operated up to their contingency ratings.

III. FUNCTIONALITY OF SIPS

The WSB SIPS has been designed to monitor 36 transmission lines and coordinate with three paired generator sites and a BESS to runback and ramp-up generation during contingency events. To detect overloads, determine the appropriate response, and coordinate multiple assets in real time, the WSB SIPS functions within three operative conditions, as shown in Table II.

TABLE II
OPERATIVE CONDITIONS

Condition	Description
A	<p>A monitored line is loaded higher than its contingency rating, and the measured frequency is healthy (indicating elevated line load conditions). In this condition, SIPS will signal the</p> <ul style="list-style-type: none"> – Paired generator(s) to runback at 3 MW/s or trip – WSB to increase battery discharge at 3 MW/s
C	<p>A monitored line is loaded higher than its contingency rating, and the frequency is low (indicating a trip of a generator). After no time delay, the SIPS will signal the</p> <ul style="list-style-type: none"> – WSB to increase battery discharge to 700 MW/s
D	<p>A monitored line is loaded higher than its 5-minute emergency rating, and the measured frequency is healthy. In this condition, SIPS will signal the</p> <ul style="list-style-type: none"> – Paired generator(s) to runback at 3 MW/s or trip – WSB to increase battery discharge at its maximum rate

The condition of the scheme is determined by the line-loading status of each monitored line, along with the system frequency measurement at the central controller site. Of the three operating conditions, Condition A represents the most common mode of operation, occurring when a line overload is detected under healthy frequency conditions.

As illustrated in Fig. 3, when the system is armed, a monitored line can be loaded to its contingency rating. After a network event, if the monitored line loading surpasses its contingency rating, SIPS initiates a timer of 35 seconds to account for auto reclosure of the faulted line. If the overload persists, SIPS enters the Condition A operating state, and the central controller simultaneously sends a runback signal to the paired generator associated with the line and an increase discharge signal to the WSB. Once the line loading on the monitored line falls below the normal rating for 5 seconds, the paired generator is required to hold its output for three NEMDE dispatch intervals (15 minutes), and the WSB must hold generation for 5 NEMDE dispatch intervals (25 minutes). Fig. 3 also shows the behavior of the power output on the respective assets: while the paired generator power profile

decreases, the WSB discharge output increases, maintaining their combined power output constant at all times, as the overload is removed.

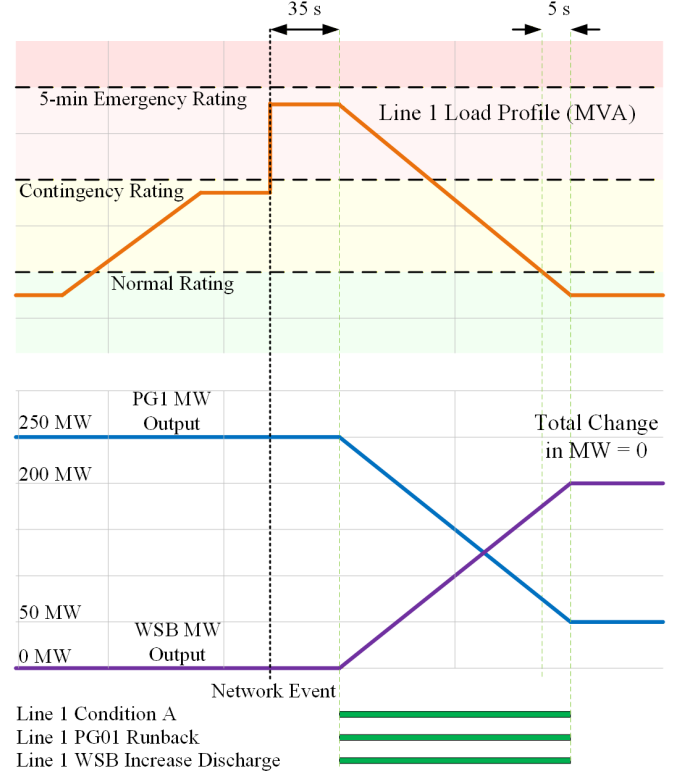


Fig. 3. Line Profile Example and PG and WSB Power Output Behavior

The WSB SIPS operates in cycles, with each SIPS cycle being initiated by a line overload event when SIPS is armed. The interactions between the operating conditions, runback sequences, generator trips, and reset logic are captured in the core SIPS function flowchart shown in Fig. 4. The flowchart illustrates the decision logic executed by the scheme for each monitored line, from initial scheme arming through to overload detection, condition classification, paired generator and BESS response, and, ultimately, scheme reset.

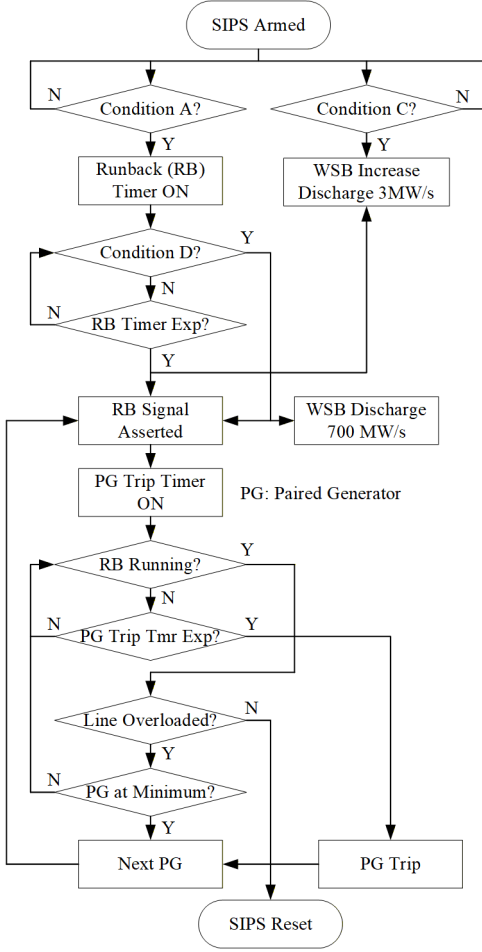


Fig. 4. SIPS Function Flowchart

To manage the different capabilities and design features, the WSB SIPS design was split into the following classifications:

- Central Controller Site (Type 2): The centralized decision-making node responsible for issuing runback and ramp-up commands to the battery and paired generators during a contingency event.
- Line-Monitoring Sites (Type 1A): Substations or switching stations where the loading of a monitored transmission line is measured.
- Battery Site (Type 1B): The substation serving as the point of connection for the WSB BESS.
- Paired Generator Sites (Type 1C): Substations serving as the points of connection for each generator contracted to participate in the SIPS.

Following these classifications, the key functions required for each site type were identified, with each function being divided into specific control tasks and inputs and outputs of each task defined. This allowed for the independent design, development, documentation, and testing of each function. The separate functions are shown in Fig. 5.

Of these function blocks, several relate directly to the interaction of the SIPS with the Battery Site (Type 1B). However, the BESS internal controlling logic remains outside the scope of the SIPS. The role of the SIPS is limited to issuing a command signal requesting the BESS to increase its active

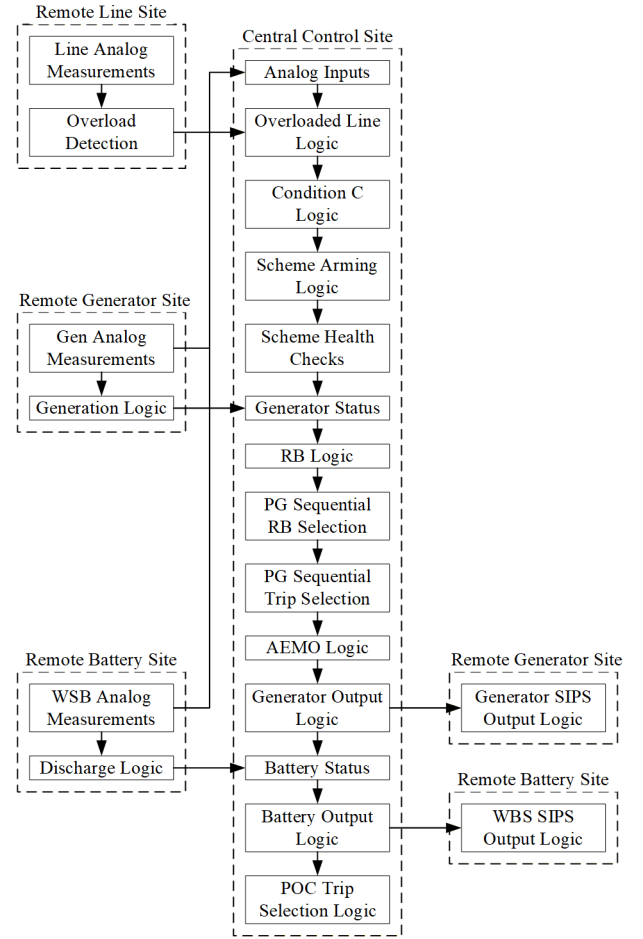


Fig. 5. Key Functions Required by Site

power discharge. The BESS controller is responsible for executing this command into the required power response. Consequently, the interaction between the SIPS and the BESS is limited to the exchange of the command signals and the healthy/ready feedback provided by the BESS, with the corresponding function blocks defining how these signals are generated, communicated, and validated.

The following sections describe the control logic developed for each participating site within the WSB SIPS overall scheme. The descriptions outline the key control functions, interfaces, and decision-making processes at each site, illustrating how the individual components operate together to deliver coordinated wide-area protection and control.

A. Type 2 Central Controller Site SIPS Arming, Operating, and Reset Logic

1) SIPS Arming Logic

The functionality of SIPS can be enabled by any of the service provider control room operators via SCADA. Enabling the scheme can be done when required, or if the combined power flow of all monitored lines connecting the SNW region is greater than 6,000 MW. Once the scheme is enabled, it is automatically armed when the WSB has available power, system frequency measurements are available, and the WSB is considered operative (refer to Fig. 6). A SIPS armed signal is

then sent to AEMO so contingency ratings can be used for monitored lines.

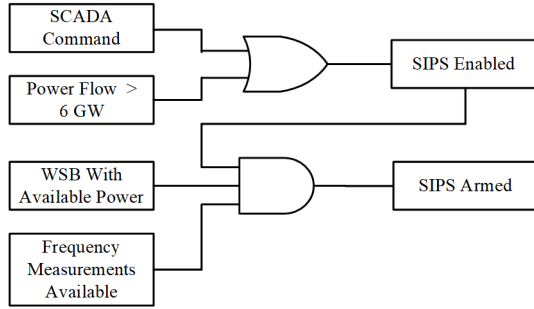


Fig. 6. SIPS Arming Logic

2) Line Arming Logic

When the scheme is armed, the WSB SIPS interfaces with AEMO to communicate which monitored lines are armed for scheme operation based on their availability (refer to Fig. 7). This information is fed into line constraint equations managed by the NEMDE that ensure the power flow on a transmission line does not exceed its allowable limit.

The limit is determined by considering the following factors:

- Whether the SIPS control scheme is armed
- The normal, contingency, and 5-minute ratings of the monitored line
- Generator healthy signals from each paired generator
- The available MW offered for SIPS by the WSB as advised via SCADA
- The available MW offered for SIPS by each paired generator, determined from:
 - The SCADA-measured MW at the start of the dispatch interval
 - The difference between the SCADA-measured MW at the start of the dispatch interval and the potential minimum output at the end of a SIPS cycle

When any single line initiates a SIPS cycle, the armed signal for all monitored lines drops out, indicating to AEMO that standard line ratings should be applied across all lines for the duration of the cycle.

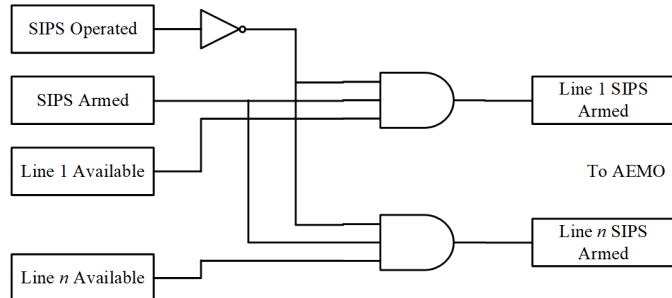


Fig. 7. Individual Line Armed Status Logic

3) SIPS Operating Logic

A SIPS cycle is initiated when one of the lines becomes overloaded (refer to Section III.B—Type 1A Line-Monitoring Sites Logic for details). Once the scheme has initiated a

response, the SIPS operated element is latched (refer to Fig. 8). This element serves four purposes:

- It provides a SCADA indication that a SIPS cycle is currently in progress
- It is used as an input to the line arming logic to signal to AEMO that the scheme constraint equations should not be applied for the duration of the cycle
- It is transmitted to paired generator sites to trigger measurement of the total generation reduction accumulated over the SIPS cycle (refer to Section III.C—Type 1C Paired Generator Sites Logic for details)
- It is transmitted to the battery site to trigger measurement of battery discharge accumulated over the SIPS cycle

The latched element is reset by the SIPS reset element.

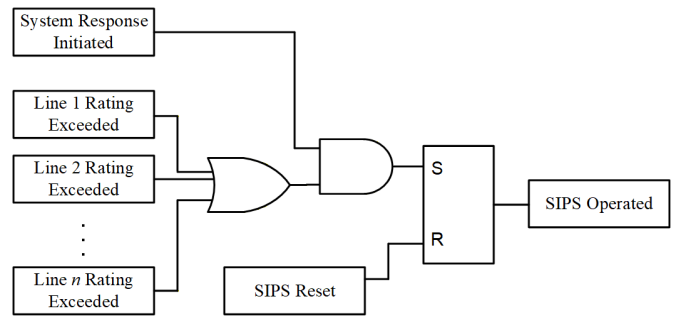


Fig. 8. SIPS Operated Logic

If a second transmission line overload occurs while a SIPS cycle is already in progress, the system does not alter its current operating state. If the subsequent overload occurs on the same transmission corridor and is associated with the same paired generator, the runback action already in progress will inherently mitigate both overload conditions. This is because the remedial action consists of reducing the output of the paired generator contributing to the overload, thereby decreasing power flow on the affected corridor.

Conversely, if the second overload occurs on a different transmission corridor associated with a different paired generator, mitigating the event would require initiating an additional generator runback. Such a response would create an imbalance between the rate of generation reduction and the compensating battery injection. For example, two paired generators each reducing output at 3 MW/s would result in a combined generation reduction rate of 6 MW/s, whereas the WSB system would continue to inject power at only 3 MW/s. This mismatch could adversely affect system power balance and the intended operation of the scheme.

Management of such events is deferred to other protection, control, and system security schemes operating within the wider power system.

4) SIPS Reset Logic

A SIPS cycle can be reset in one of two ways: automatic reset and manual reset.

a) Automatic Reset

The automatic reset monitors the SIPS operated latch element. When the line overload is cleared, a reset timer is started (refer to Fig. 9). The timer is latched from the first instance a line overload is removed; subsequent overloads on other lines during the same cycle do not restart the timer. The timer is set to 25 minutes, corresponding to 5 AEMO dispatch intervals, which, together with the 5-minute battery discharge increase period, gives a total SIPS cycle time of 30 minutes.

b) Manual Reset

A manual reset can be initiated by the control room via a SIPS reset command. This is used when the system has stabilized—that is, overloads have been cleared and generation runback and battery discharge are on hold—and the control room wishes to return to normal operations.

The SIPS reset element resets the following:

- The SIPS operated latched element
- The reset timer latched element
- The generator sequence complete logic for each paired generator
- The line overload event element for each monitored line

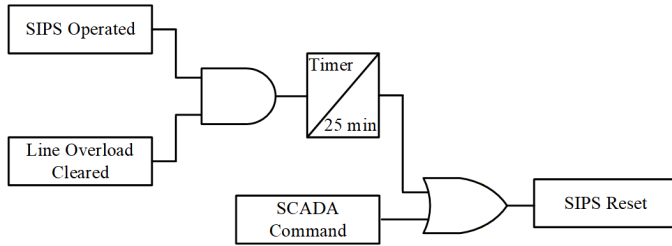


Fig. 9. SIPS Reset Logic

B. Type 1A Line-Monitoring Sites Logic

Monitoring sites perform a focused function: measuring line loading and communicating its status to the central controller. Static line ratings, sourced from the service provider's operating manuals, are programmed as look-up tables into each of the IEDs at the remote monitoring sites. The IED measures raw analog data from each monitored CT and VT circuit and calculates an MVA value to determine the line loading. Where applicable, it also applies a loss factor to allow for single-end monitoring of the line. The measured power is compared against the seasonal line ratings to determine whether the normal, contingency, or 5-minute rating has been exceeded, and the IED raises the associated flag, as shown in Fig. 10. The rating exceeded flag is then forwarded to a central controller as a virtual bit signal via serial communications. Rating exceeded flags from multiple overloaded transmission lines may be transmitted concurrently.

A health signal for each monitored line is also transmitted to the central controller to confirm data validity. For monitoring sites, this signal is a logical combination of the IED internal fault, IED power supply fail, VT fail, and CT/VT card failure conditions. If any of these conditions are active, the health signal de-asserts and the central controller treats the affected

line as inoperative, preventing the scheme from being triggered from this monitored line.

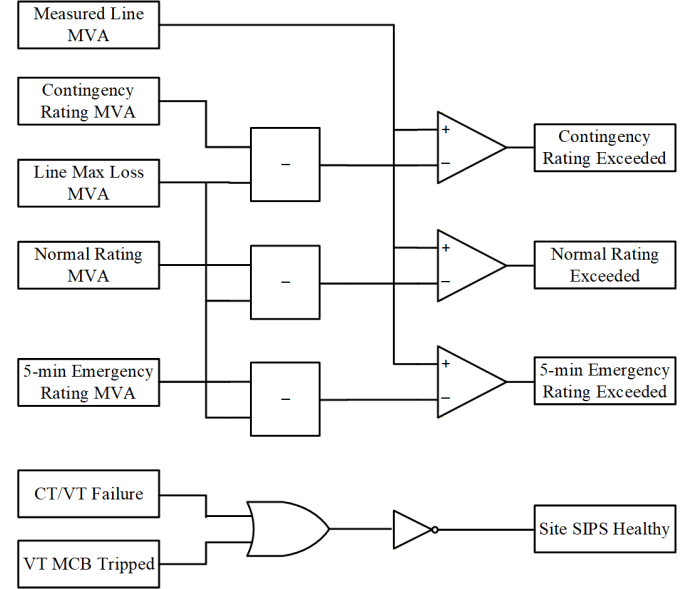


Fig. 10. Health Verification of Ratings and Field Measuring Devices

C. Type 1C Paired Generator Sites Logic

Paired generator sites interface the central controller with each participating paired generator and provide the logic required to execute and monitor generation runback during a contingency event. The logic is responsible for:

- Determining the required runback quantity and ramp rate for each SIPS cycle
- Monitoring whether the generator has reached its minimum output or generation has been exhausted
- Performing a final check prior to issuing a generator trip command

1) Paired Generator Initialization

At the start of each SIPS cycle, the generator site logic performs a series of initialization checks and records the system state. During normal operation, power flow is directed toward the busbar at the point of connection (POC).

At the start of the SIPS cycle, the following actions are taken:

- An element is set to confirm the generator was healthy at the start of the cycle. AEMO line-loading calculations assume the availability of each paired generator, so each unit is expected to respond to runback commands. Generator tripping is blocked if this element is not set at initialization.
- An element is set to indicate that a SIPS cycle is in progress.
- The available generation capacity is recorded at the point of cycle commencement.
- The measured POC power is recorded as the reference value for subsequent runback monitoring.

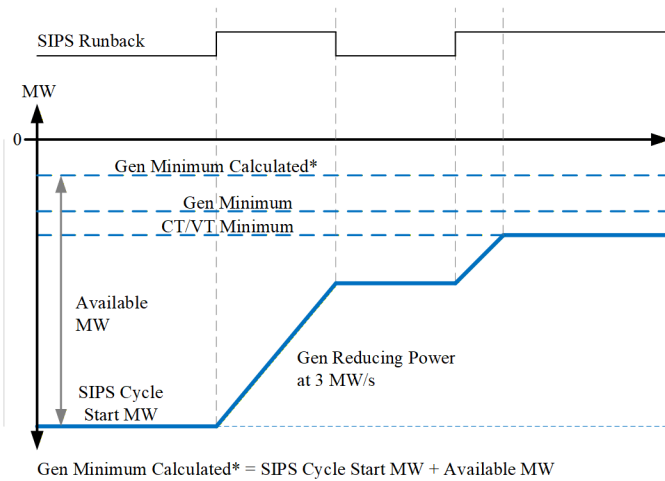


Fig. 11. Generator Capacity Calculation (Available MW)

2) Paired Generator Runback Monitoring Logic

Using real-time POC power measurements, the runback monitoring logic evaluates whether the paired generator is reducing at an adequate rate. The required ramp rate is determined by sampling the measured POC power at fixed intervals and comparing the calculated rate of change against the required generation reduction ramp rate. The ramp rate performance is assessed using three methods:

- **Slow-Start Reduction:** Each generator is contracted to respond to a runback signal within an agreed time called the guaranteed response timer. To guard against the slow initial response of the generator following expiry of the guaranteed response timer, a simple check determines whether generation is reducing. This check is active for the first 10 seconds of the runback event, after which the generator is expected to be ramping at or above the required rate. The slow-start reduction element is set for a maximum of 10 seconds. To prevent spurious operation observed during commissioning, the underlying reduction detected element requires 2 seconds of continuous assertion before the slow-start reduction element is set.
- **Ramp Rate Adequacy:** The sampled ramp rate is compared against the required generation reduction ramp rate. If the sampled rate meets or exceeds this threshold within a 10 percent tolerance, the generation reduction is considered adequate and the reduction adequate element asserts. To prevent spurious operation observed during commissioning, this condition must remain continuously true for 2 seconds before the reduction adequate stable element is asserted.
- **Average Power Reduction:** The average power reduction element is introduced to handle non-linear generator responses. During commissioning, the hydroelectric plant exhibited a sawtooth MW profile that, while broadly linear, produced variable instantaneous ramp rate measurements depending on the point of sampling. The wind farm response was also non-linear, as variations in wind speed caused the

measured ramp rate to fluctuate, leading to oscillatory controller behavior. To mitigate this, the average power reduction is calculated by comparing the actual measured reduction against 90 percent of the target reduction accumulated over the duration of the runback event. The average MW reduction adequate element is asserted when this condition is met, the reduction detected element is stably set, and the generator has not reached its minimum output.

A POC reducing signal is transmitted to the central controller to indicate that the paired generator is responding as expected. The signal is asserted when any two of the three monitoring subelements—slow-start reduction, ramp rate adequacy, and average power reduction—are satisfied simultaneously.

The runback monitoring logic evaluates the measurement signals only when all the following conditions are true:

- A runback event is in progress, and the guaranteed response timer has expired
- The generator has not reached its minimum output
- The generator was confirmed healthy at the start of the SIPS cycle

When these conditions are met, the real-time target MW reduction and the measured runback MW reduction are calculated and recorded respectively. If the generator reaches its minimum output during the event, the target and actual MW values are retained at their last valid state rather than reset.

During an active runback event, the target and actual values are updated continuously. If the scheme is paused, the measured reduction is set to zero, as no further runback is expected for that instance.

3) Paired Generator at Minimum Generation

The minimum generation limit for each paired generator is calculated as the greater of two values: the minimum generation floor specified by the paired generator to prevent plant shutdown, or the minimum measurable power derived from the CT/VT card current input limitation at the service provider's POC. This logic feeds into the generator sequence complete logic, which allows the scheme to automatically runback the next paired generator associated with the overloaded line.

4) Paired Generator Runback Event End Logic

A single SIPS cycle may contain multiple runback events, either on the same overloaded corridor line or on different corridor lines. At the end of each event, the following actions are performed:

- A flag is set to indicate that the runback event has ended
- The runback start reference value is reset
- The target MW reduction achieved during the event is recorded
- The actual MW reduction achieved during the event is recorded
- The values are retained for use by the central controller in subsequent runback events within the same SIPS cycle

5) Paired Generator Sequential Logic

The paired generator sequential logic enables the WSB SIPS to automatically runback generators in a defined order during a SIPS cycle (refer to Fig. 12). During the planning phase, network studies were used to establish a priority list of paired generators for each monitored line. When a line overload is detected, the highest priority generator associated with that line is signaled to runback first. If the overload persists, the scheme progresses through the priority list in sequence until the overload is cleared.

The paired generator sequential logic relies on a generator availability check, a generator runback fail check, and a generator sequence complete status to determine its runback commands.

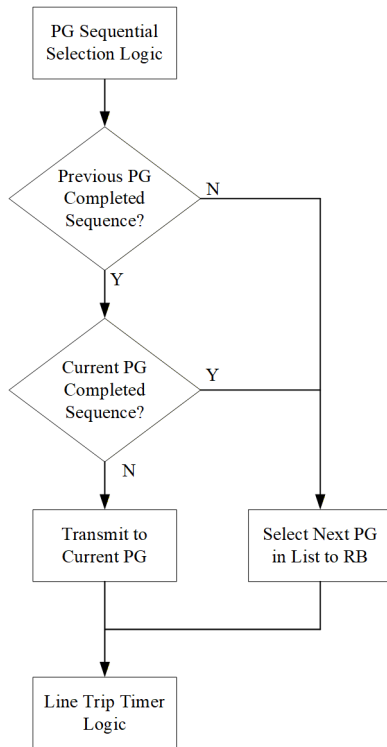


Fig. 12. Paired Generator Sequential Selection Logic

6) Paired Generator Availability

The generator availability element is a latched signal used by the central controller for three purposes: to establish whether the scheme should advance to the next paired generator in the runback sequence, determine whether a paired generator is eligible to be tripped if required, and pass the runback and trip signals to the remote generator site.

The element is set when the generator is enabled and not inoperative at the start of a SIPS cycle. It is reset only if SIPS is disabled or inoperative prior to a SIPS cycle commencing. Once a SIPS cycle has commenced, the availability status is latched and cannot be altered by operator action or by an inoperative signal asserted mid-cycle. This is intentional, as the

NEMDE line constraint calculations rely on the availability of each paired generator, and the scheme is designed to reflect the system state that existed at the start of the cycle.

7) Paired Generator Runback Fail

A generator is classified as failed if the measured POC power is not reducing adequately following expiry of the guaranteed response timer after the runback signal has been issued. The generator failed element is blocked under any of the following conditions:

- The generator has reached its minimum output, indicating it has fulfilled its runback obligation
- The generator was not available at the start of the SIPS cycle
- The WSB is inoperative—if the BESS fails during a runback event and neither the battery discharge nor generator runback signals can be executed, the generator is not classified as failed for that event

If none of these blocking conditions apply and the generator continues to fail to respond, a latched generator fail signal is set after 5 seconds.

The generator fail element can only be reset by the control room, following confirmation from the generator operator or control technicians that the underlying cause has been resolved. If a subsequent runback event occurs while the generator remains in a failed state, a reduce generation signal is still issued to that generator; however, the scheme immediately considers the runback sequence for that unit complete and advances to the next priority paired generator for the overloaded line.

8) Paired Generator Sequence Completion

The generator is considered to have completed its runback sequence when any of the following conditions occur after the runback signal has been issued:

- The generator runback fail element is set
- The generator was not available at the start of the cycle
- The generator has reduced to its minimum MW output as advised by the generator
- The measured POC power has reached the minimum MW threshold

Once sequence completion is determined, the scheme selects the next priority paired generator for the overloaded line. The reduce generation signal remains active to all paired generators until the line overload is cleared.

9) Paired Generator Tripping Logic

Generator tripping is used as a last resort when line overloads persist despite sequential generation runback during a SIPS cycle. If a paired generator fails to runback as expected, the generator runback fail element places that generator on a priority-based trip list. The scheme then works through the list in sequence until the line overload is cleared (refer to Fig. 13).

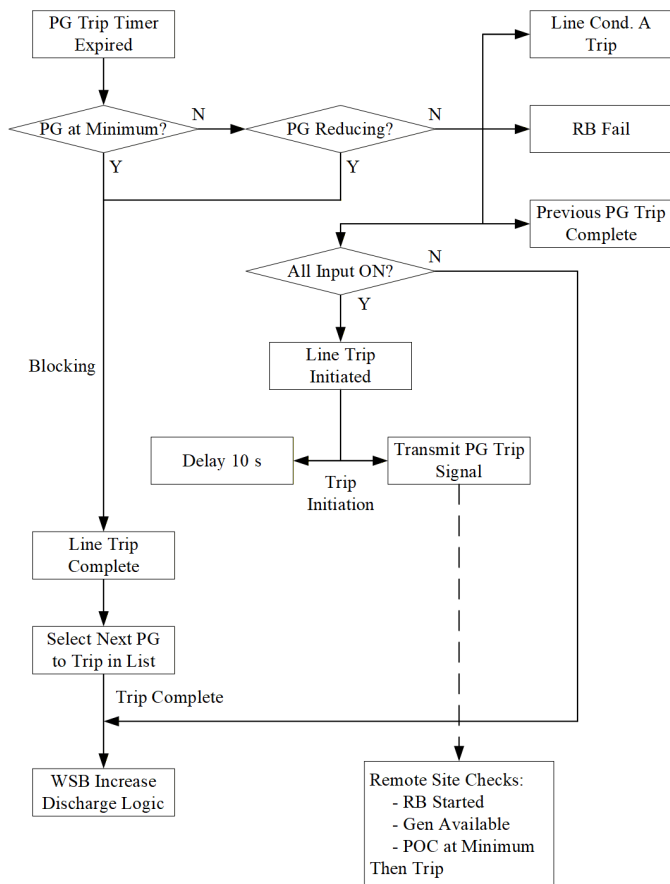


Fig. 13. Paired Generator Tripping Logic

a) Trip Initiation

A trip signal is issued to a paired generator when all the following conditions are met:

- The line overload element for the associated monitored line is set and remains set until the overload is cleared
- The generator runback fail element is set, indicating the generator has not responded adequately as determined by the SIPS measurement circuits
- The trip complete element for this generator is not set, confirming a trip has not already been issued, and the generator has not been blocked from tripping

The trip signal is implemented as a latched element, ensuring the generator can only be tripped once per SIPS cycle. The latch is reset by the SIPS reset element.

b) Trip Blocking

A paired generator trip signal is blocked if either of the following conditions is met:

- The measured POC power has reached the minimum output of the generator, indicating that no further generation reduction is available for the current SIPS cycle
- The measured POC power is reducing at an adequate rate, indicating the generator is responding as expected

Both conditions are evaluated from measured POC values rather than feedback signals from the generator.

c) Trip Cycle Completion

A paired generator is considered to have completed its trip cycle when either of the following conditions is met:

- The trip initiation element has been latched, and the trip timer of 10 seconds has expired. This delay provides a minimum 10-second interval between successive trip signals
- The generator trip blocking element is set, in which case the trip cycle is considered complete without a trip being issued

Once a generator trip cycle is complete, the scheme advances to the next priority generator for the overloaded line. Advancement occurs after the trip timer delay if a trip was issued, or instantaneously if the generator was blocked.

IV. DESIGN DETAILS AND FEATURES

With delivery required within 2.5 years, ahead of the planned retirement of the 2.8 GW coal-fired power station, two primary design requirements drove the design process: maximizing reuse of existing infrastructure and adopting a modular architecture capable of accommodating additional monitored lines and paired generators as the scheme evolves.

Despite the broad scope of the WSB SIPS—spanning 36 monitored lines, three paired generator sites, a BESS, and a wide-area communications network—the design was kept deliberately simple. Basing the scheme on the service provider's existing Special Protection Scheme (SPS) standard and leveraging infrastructure already present across the network avoided the need for bespoke hardware. Standard panel designs, familiar equipment, and the existing communications topology formed the basis of the scheme, with site-specific modifications applied only where required.

This approach reduced engineering complexity, compressed delivery timelines, and produced a design well understood by both design engineers and field technicians. The following sections describe the equipment selection, panel design, site locations, and communications network that underpin this design approach.

A. Selection of Equipment

The existing SPS standard uses automation controllers to enable communications between sites, and modular I/O racks with digital, CT, and VT input capabilities to measure current and voltage and monitor circuit breaker statuses. Communications between sites use a secure high-speed serial communications protocol for simple commissioning and to ensure a modular and expandable design.

1) Automation Controllers

SIPS employs automation controllers (ACs) installed at both the central and remote Line-Monitoring and Paired Generator sites to provide deterministic monitoring, decision-making, and coordinated control. Each remote-site AC interfaces with distributed I/O racks to acquire real-time information from field equipment, including circuit breaker statuses, protection indications, and line measurements. Digital input modules acquire binary field signals, while analog input modules acquire CT, VT, and other electrical measurements to support the SIPS

monitoring and automation logic. The central AC receives information from all remote sites, providing a consolidated system-wide view for contingency assessment and remedial action.

The ACs communicate via the DNP3 protocol to exchange analog signals and use a secure high-speed peer-to-peer communications protocol for digital signals, enabling deterministic exchange of critical system information, including transmission line outages, generator statuses, and circuit breaker positions. Based on this information, the central AC executes the SIPS algorithms and coordinates corrective control actions required to maintain power system stability following major network contingencies. Corrective actions, including generation runbacks, BESS increase discharge, and generator trips, are transmitted to the appropriate remote AC for execution.

The ACs provide an IEC 61131-3-compliant execution environment, integrating real-time data acquisition and programmable automation within a modular architecture. By centralizing system assessment and remedial action logic while distributing field monitoring and control functions to the remote ACs, the architecture shown in Fig. 14 provides a scalable, maintainable, and easily expandable solution that preserves deterministic and reliable performance, simplifies system maintenance, and supports future network expansion.

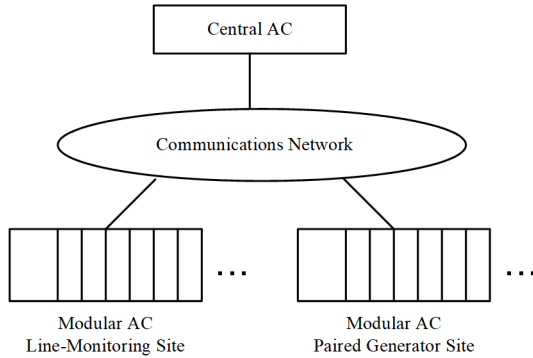


Fig. 14. Simplified Architecture of ACs

2) Secure High-Speed Serial Communications

Secure high-speed serial communications are achieved over a time-division multiplexing (TDM) network, which encapsulates the digital statuses into TDM frames mapped to a predefined time slot within the communications frame. This method allows the transport of serial information maintaining the deterministic delay characteristics required for protection applications.

The protocol used allows up to eight user-programmable bits to be transmitted between devices, making it well suited for protection, control, and monitoring applications requiring deterministic and dependable communications.

The protocol operates by mirroring the status of eight transmitting bits (TXB) in a sending device to corresponding eight receiving bits (RXB) in a destination device over a serial communications channel (refer to Fig. 15). Each TXB can be assigned to any internal bit status within the sending device, allowing logic states to be communicated directly between IEDs. Under normal operating conditions, the status of each

RXB accurately reflects the status of its corresponding TXB, enabling distributed logic execution, interlocking, transfer tripping, and remedial action schemes.

This type of communications is designed for high-speed operation, with message transmission and processing occurring at the IED processing interval, enabling subcycle performance in many applications. To ensure dependable operation, the protocol incorporates error detection, message validation, and continuous channel supervision. Communications failures or channel degradation are promptly detected and alarmed, allowing applications to respond appropriately to loss of communications.

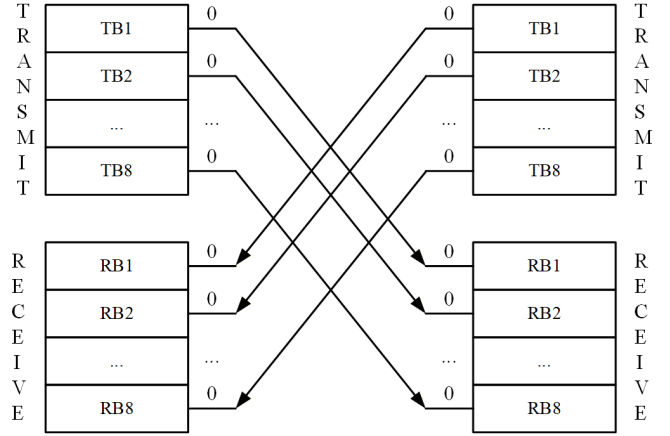


Fig. 15. Secure High-Speed Serial Communications Transmission and Reception

B. Panel Design

The service provider's SPS standard employs a half-panel design housing an AC device within its modular I/O rack connected via EtherCAT protocol. The design is duplicated to provide fully independent No. 1 and No. 2 systems, each with separate power supplies, analog measurement circuits, and digital input and output infrastructure.

At monitoring sites, line loading is determined by measuring line current and voltage via the CT/VT cards on the modular I/O rack of the AC. While the standard permits connection from dedicated metering-core CT circuits, this requires new cabling from the switchyard to the control room. As monitoring sites do not require high measurement accuracy, the CT/VT analog inputs are instead sourced from the existing protection circuits of the monitored line. As shown in Fig. 16, CT signals are taken from the line protection panel, with the CT star point relocated to the modular I/O device, eliminating the need for new switchyard cabling across all 14 monitoring sites. Each AC modular I/O device is fitted with a power supply module, a 24-input digital card, a binary output card, and two protection-grade CT/VT input cards.

The panel design for the Type 1B and 1C sites follows the same standard as the Type 1A monitoring sites. Two half panels, housing the AC modular I/O rack, were installed at the new battery site, with corresponding modifications made at each existing paired generator site. To capture the battery ramp from 0 MW with sufficient accuracy, metering cards were also

installed at this site, with cabling run from the metering cores to provide the required measurement sensitivity.

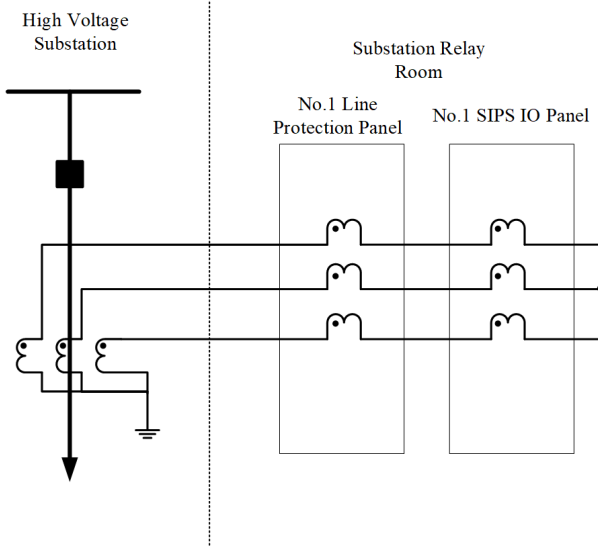


Fig. 16. CT Signal Connections

C. Communications Network

The WSB SIPS scheme required reliable communications infrastructure so the central controller site could continuously communicate with all 14 line-monitoring sites, the paired generator sites, and the BESS site.

The service provider's existing communications network is primarily comprised of optical ground wire and microwave bearers and is structured as a series of interconnected rings. The central automation controller site was located at the intersection of the two northern rings and the southern section of the network, satisfying the requirement for communications connectivity to all remote sites and locating it close to load demand for accurate frequency measurements.

Full communications duplication was also a strict requirement of the WSB SIPS design. Monitoring is provided by duplicate No. 1 and No. 2 systems, but these systems are not route diverse—both rely on the same communications path. Actioning, by contrast, is provided by duplicate systems that are also route diverse, so that a corrective command can still reach its destination via an alternate path if one route fails. This distinction matters because the base architecture does not natively support the many-to-one and one-to-many communications flows required by the SIPS, where loading status data are received from multiple monitoring sites and corrective runback and ramp-up commands are issued outward to the paired generator and battery sites.

As shown in Fig. 17, a failure of a single communications link affecting monitoring can result in one of the two protection systems failing to initiate, since monitoring is not route diverse. However, because actioning is duplicate and route diverse, if either system does initiate, its corrective signal will still reach the actioned site—even if one of the paths to that site is affected by the same link failure. In other words, a single link failure may prevent both protection systems from initiating and operating simultaneously, but it will not prevent an initiated system action signal from reaching its destination.

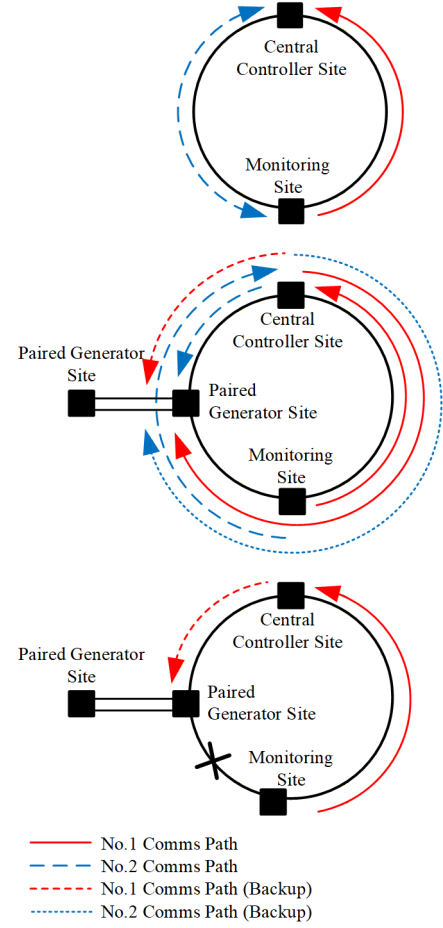


Fig. 17. Communications Network

V. TESTING AND COMMISSIONING

Testing and commissioning of the WSB SIPS was a key consideration from the earliest development meetings. Ensuring that the design allowed a staged rollout of the initial scheme as well as smooth integration of future changes was the primary focus and the Engineering and Commissioning teams worked hand-in-hand to deliver a product that was efficient to operate.

Due to limited availability of site installation and field commissioning personnel, the decision was made to accelerate rollout of the low-risk line-monitoring sites while final development of the central processing and generator POC site configurations continued.

The commissioning process was split into eight stages:

- Laboratory configuration testing: Using site-specific configurations and relay test instructions to validate metering, alarms, statuses, analogs, timing, tripping sequences, and control logic before deployment to site.
- Laboratory end-to-end testing: Using a SIPS simulator to replicate BESS and paired generator interfaces, allowing normal and abnormal response scenarios to be tested before field implementation.
- Hardware installation testing: Confirming that panels, cabling, IEDs, and associated site equipment are

installed in accordance with the approved design and are ready for functional testing.

- Site functional testing: Confirming that proven laboratory configurations operate correctly on installed field equipment and that local HMI and SCADA points are correctly represented.
- Communications testing: Verifying that the required communications paths are established between the central control location and remote monitoring, BESS, and paired generator interfaces.
- Interface testing: Confirming agreed signal exchanges with AEMO, the BESS service provider, and each paired generator provider.
- Scheme end-to-end site testing: Confirming the complete signal path, including monitoring site processing, communications latency, central logic processing, and downstream POC response. This testing was completed by stationing technicians at the paired generator and battery sites with other technicians traversing the line-monitoring sites to complete satellite synchronized testing for all combinations of line overload/paired generator availability.
- Integrated in-service testing: Simulating a monitored line overload condition in the live scheme to verify coordinated BESS discharge, paired generator runback, communications path performance, and reduction of transfer on the monitored circuit.

The commissioning process began in January 2024 and culminated with successful integrated network testing in July 2025. With SIPS now in service, scheme behavior and generator compliance with the scheme is monitored and stored in a separate monitoring IED.

VI. FUTURE EXPANSION

The WSB SIPS is expected to undergo further expansion as additional projects interact with the scheme. More than a dozen renewable energy projects involve new switching stations connecting into SIPS-monitored transmission lines, which will require additional line monitoring for the new line sections created. A further project is underway to add a new paired generator site, and separately, a project to modify the WSB functionality is being considered, using a SIPS reservation process.

To support this growth, an additional AC will be required to accommodate the increased number of communications links and serial port requirements associated with these expansions.

VII. CONCLUSION

The SIPS demonstrates how wide-area automation can be applied to increase transmission network utilization while maintaining secure system operation during the transition to a renewable-based power system. By coordinating the response of geographically distributed transmission assets, paired generators, and the WSB BESS, the scheme enables monitored transmission lines to operate at contingency ratings and rapidly

restores the network to a secure operating state following major contingencies. This capability provides additional transfer capacity, reduces network constraints, and improves the utilization of existing transmission infrastructure.

The modular architecture adopted for the WSB combines distributed monitoring with centralized decision-making through ACs communicating over a deterministic, high-speed communications network. The use of standardized hardware, IEC 61131-3 programmable automation, and reusable design modules enabled rapid development, simplified testing and commissioning, and produced a scalable solution that can readily accommodate additional monitored transmission lines, generators, and future network developments. Leveraging existing Transgrid SPS standards and infrastructure also reduced implementation complexity and delivery risk while maintaining high levels of reliability and maintainability.

The successful commissioning and operation of the WSB SIPS demonstrates that modern SIPS can provide an effective and practical alternative to traditional operational constraints as transmission networks evolve. The design methodology presented in this paper establishes a repeatable framework for developing large-scale wide-area remedial action schemes, supporting the integration of renewable generation and energy storage while maximizing the capability of existing transmission assets. As additional renewable projects and network augmentations are commissioned, the modular architecture of the WSB SIPS provides a robust foundation for future expansion and continued enhancement of power system security and operational flexibility.

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IX. BIOGRAPHIES

Pratiksha Chuttar is an intermediate design engineer with Transgrid, based in Ultimo, New South Wales. A graduate of the University of Technology Sydney (2020), she has spent five years at Transgrid working across disciplines in Network Operations, Construction, Project Development, Protection, Control, and Automation. Pratiksha has contributed to several complex transmission projects, including the Waratah Super Battery System Integrity Protection Scheme (WSB SIPS), where she supported the design and documentation of protection and automation logic. Her interests include power system protection, automation, system integrity protection schemes, and renewable energy integration.

Simon Wallace is a senior commissioning engineer within Transgrid's Construction Technical Services team, based in Newcastle, New South Wales. He specializes in the commissioning, testing, and integration of protection, control, communications, and wide-area automation systems across the Australian high-voltage transmission network, with experience spanning renewable energy integrations, battery energy storage systems, system integrity protection schemes (SIPS), substation automation, and IEC 61850 communications. Simon has played a key role in the delivery of major transmission projects, including the Waratah Super Battery SIPS, and is also active in commissioning strategy and technical capability development, with a focus on practical engineering solutions that enhance power system security, reliability and resilience.

Michael Illes was the senior design engineer for the SIPS project implemented by Transgrid to increase the transfer of power in the 330kV transmission network. He has been a design and commissioning engineer for 15 years and engineering manager for 5 years at Ausgrid in the field of subtransmission and distribution. He is now a principal engineer for Del Engineering and senior secondary design engineer for Transgrid for the past 7 years, specializing in design and implementation of special protection schemes for a variety of runback and transfer tripping schemes.

Jahangir Safari is the control and automation design manager at Transgrid, where he leads the development and delivery of protection, control, automation, and grid-control solutions. He guides multidisciplinary teams in designing critical power system infrastructure, with expertise in power system protection, substation automation, and wide-area control systems. Jahangir has led major projects, including the Waratah Super Battery System Integrity Protection Scheme, translating complex operational requirements into secure, resilient engineering solutions. He is an active contributor to power system protection and automation practices, with particular interests in digital substations and wide-area protection schemes.

Alvaro Pastrana received his BS degree in electrical engineering from Universidad del Valle, Colombia, in 1995. In 2008, he joined Schweitzer Engineering Laboratories, Australia as project engineer, as part of the Engineering Services team. In 2016, he took a new role working as application engineer, assisting customers in substation automation and communications.

Daniel Fiorini da Silva graduated in Electrical Engineering from the Universidade Tecnológica Federal do Paraná (UTFPR) in 2014 and completed his specialization in Protection of Power Systems in 2016. He has more than 14 years of experience in the power systems industry, with expertise in power system protection, automation, and control, supporting utilities and industrial customers in the application of advanced protection technologies.