Advanced Synchronizing Systems Improve Reliability and Flexibility of Offshore Power Systems

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ADVANCED SYNCHRONIZING SYSTEMS IMPROVE RELIABILITY AND FLEXIBILITY OF OFFSHORE POWER SYSTEMS

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Abstract—Small power systems such as those found on offshore platforms are fragile; yet, they must operate reliably for economy and safety for personnel and the environment. These systems often include combustion turbine generators for main process power requirements and black-start diesel generators that can supply essential and emergency buses and be used to restart the main generation in the event of a power system collapse. The power distribution systems on these offshore platforms have built-in redundancy with multiple circuits to supply critical loads for fault tolerance and operating flexibility. A system to easily and safely synchronize islanded buses via many possible synchronization points can revolutionize the operational flexibility and therefore the safety and reliability of the power system. This paper reports on advanced synchronizing systems installed on two offshore platforms.

Index Terms—Automatic synchronizer, offshore power, synchronizing, reliability islanding, black-start, critical loads.

I. INTRODUCTION

Two deep-water platforms are being constructed in parallel projects. The electric power systems on these platforms are similar in design. The power generation and distribution systems for this application have to be extremely flexible, robust, and fault-tolerant to meet the requirements of economy, compliance with regulations, and safety for personnel and the environment.

The focus of this paper is the advanced automatic synchronizing system that enables the flexibility to island critical load buses to ensure continuous supply and then resynchronize these load buses back to the main generation systems as needed. The synchronizing system eliminates the need for momentary outages during transition from one power source to the next.

The paper first describes the two platforms. Then, an overview of the power management and load-shedding system that helps the power system survive a sudden loss of generation without collapsing is discussed. Finally, the paper focuses on the challenges of providing flexible synchronizing systems and the two similar but unique solutions implemented on each platform.

II. BACKGROUND

The power generation system for the two platforms is similar. Each platform is capable of generating about 76 MW with three combustion turbine generators. The main generators are connected to a 13 kV switchgear lineup, which then distributes power to the loads through transformers feeding 4,160 V and 480 V switchgear and motor control centers (MCCs). These main generators are backed up by two 480 V diesel standby generators that can be used to supply critical load buses and black-start the power system in the event of a complete loss of the main power supply.

A. Platform 1: Production Platform

Platform 1 is a semisubmersible floating production unit (FPU) equipped with production facilities, a full complement of utilities, and accommodations. It is designed to process up to 170,000 barrels of oil per day (BOPD) with provision for future expansion. The FPU has the following two main components:

1. The hull, which is a semisubmersible type and is equipped with all the required marine systems.
2. The topsides, which consist of three modules—generation, production, and compression—where most of the process equipment is located.

B. Platform 2: Drilling and Production Platform

Platform 2 is an extended tension leg platform (ETLP) equipped with various oil and gas processing systems, including gas compression, oil and water treatment and export and utility systems, and accommodations. It is designed with a production capacity of 75,000 BOPD and 25 million cubic feet of natural gas per day. The power generation facilities are similar to Platform 1. The 480 V switchgear is arranged with a hurricane switchboard, an essential switchboard, and an emergency switchboard. The essential switchboard has ties to both the emergency and hurricane switchboards.

C. Power Generation Overview

The FPU and ETLP have three power generation systems:

1. Normal (primary) power generation.
2. Emergency power generation.
3. Hurricane power generation (black-start/hurricane for Platform 1).

1) Normal (Primary) Power Generation

Primary electrical power for both platforms is generated at 13.8 kV, three-phase, 60 Hz. Three identical dual fuel combustion turbine generator sets are located on the generation module. Electric power is fed to a 13,800 Vac switchgear lineup.

Platform 1 is a two-section bus configuration joined by two normally closed tie breakers. Generator 1 is connected to Main SWB/Bus A, and Generator 3 is connected to Main SWB/Bus B, while Generator 2 can be connected either to Bus A or B. Platform 2 has three bus sections, with one of the three combustion turbine generators connected to each bus.

Power is distributed from the main switchgear to the auxiliary loads within the generation module at 480 V and to the rest of the topside and hull modules at 13.8 kV.

2) Emergency Power Generation

Emergency electrical power is provided by a diesel engine-driven generator, located in the FPU hull for Platform 1 and on the main deck for Platform 2. The emergency generator package generates 2,125 kW at 480 V. It is sized to run all U.S. Coast Guard and American Bureau of Shipping mandated systems and critical life support, control, utility electrical loads, and platform essential loads when the primary generators are offline. All of the platform emergency loads are fed from the emergency switchgear, located in the hull. In normal conditions of operation, the emergency switchgear is fed from the main generators. The emergency diesel generator will be started automatically upon loss of voltage on the 480 Vac emergency switchgear bus.

The emergency generator can be used for black-start functions when the black-start/hurricane generator is not available.

3) Black-Start/Hurricane Generation

A black-start/hurricane generator, identical to the emergency generator, is used to furnish electrical power for startup and for the critical habitable loads when the primary generators are offline. Electrical power is normally supplied to the 480 Vac black-start/hurricane switchgear from the main turbine generators. When the turbine generators are not in service, power is supplied to the black-start/hurricane switchgear from the emergency generator.

The black-start/hurricane generator can be used to feed the emergency switchgear loads when the emergency generator is not available.

4) Summary

As described previously, the emergency and black-start/hurricane generators will respectively feed the emergency and black-start/hurricane load buses whenever the main generators are offline. Therefore, means to synchronize these critical load buses to allow a transfer from one power source to another without load shutdown are required.

Both platforms have been provided with three ways/locations from which each diesel generator can be synchronized with the main power generators:

1. From the diesel generator control panel (GCP), which is automatic and manual.
2. Locally on the front of the advanced automatic synchronizer (A25A), which is automatic only.
3. Remotely on the power management and load-shedding (PMLS) system human-machine interface (HMI), which is automatic only.

III. POWER MANAGEMENT AND LOAD-SHEDDING SYSTEM

The PMLS system has three main functions:

1. Provides system visualization, power system event records, and engineering access to the electric power system on the platform.
2. Functions as an integrated fast load-shedding system to stabilize system frequency in response to a sudden loss of generation.
3. Interfaces with the advanced automatic synchronizing system and provides users with remote monitoring and control functions.

A. Power Management System

The power management system monitors the power system status from high-level system power flow to detail the per-phase status of loads. It integrates hundreds of intelligent electronic devices (IEDs) on the platform, including protective relays, smart meters, solid-state trip (SST) units, uninterruptible power supplies (UPSs), MCCs, high-resistance grounding (HRG) monitoring systems, turbine generator control panels (TCPs), and so on.

Typical PMLS HMI screens include a power system overview, switchgear one-line diagrams, IED details, communication diagnostics, alarms and events, and trending. A great advantage offered by the PMLS system is HMI circuit breaker control. With a few clicks, the user can open or close any circuit breaker without using the umbilical switch.

The umbilical switch is a breaker control switch mounted on a cable to allow local manual control of circuit breakers from a safe distance. Use of the switch requires extra time to connect the cable before the operator can control each breaker. HMI control provides this safety enhancement while improving efficiency, visual indication to reduce human error, and convenience.

By controlling the main and tie circuit breakers in each switchgear lineup, the operator can direct the power flow, swap sources, prepare the system to be ready for certain operations (e.g., an automatic synchronizing process), and observe the live feedback after the operation process is executed.

The PMLS HMI is installed in each electrical building in various locations on the platform. The HMI uses thin client technology to increase ruggedness and reduce maintenance efforts.

The thin client technology is a network-based server-client solution. Almost all of the data processing tasks occur on server-side computers, known as terminal servers. Very little data processing occurs on the client-side computers, known as thin clients. The thin clients are set up to automatically establish remote connections with the terminal servers and to request that the terminal servers provide instructions on which application to run for the HMI. Because each thin client only needs to process a small amount of data, it requires minimal central processing unit (CPU) speed, low random-access memory (RAM) capacity, and no local storage or hard drives. This makes it possible for the thin client to use a passive device for heat dissipation and to eliminate failures caused by hard drives. As a result, the thin client hardware can be manufactured for higher ruggedness, smaller form factor, lower cost, and no housekeeping.

The software maintenance effort can be greatly reduced as well. The information technology (IT) administrator will not need to perform operating system (OS) patching or antivirus upgrades on the thin clients. All of the IT technical controls are applied on the centralized terminal servers only.

Historically, providing support to offshore operations in a timely manner has been a challenge in the marine industry due to the geographic constraint. It could require significant cost, time, and coordination effort for an electrical engineer to travel to supervise any critical operation. The power management system used on these two projects provides two onshore view nodes, one at the operation center and another at the engineering center. These onshore connections are securely protected by multiple levels of firewalls and IT demilitarized zones (DMZs) and comply with the company IT technical control policies. With high-speed subsea fiber-optic cables, a group of onshore engineers can provide support in real time on the live HMI and can retrieve and analyze the event files without the time and expense to travel offshore.

B. Load-Shedding System

The load-shedding system is configured to provide automatic intelligent load reduction in response to predetermined contingencies (loss of source). This scheme reduces the total platform load to slightly less than the calculated available capacity based on measured capacity before a contingency occurs.

In the scheme, the loads are automatically selected for shedding based on operator-configurable action tables and power system conditions. The system precalculates and selects the amount of load that matches or slightly exceeds the power deficit should that contingency occur. Upon detection of a contingency, the load-shedding controller sends out IEC 61850 Generic Object-Oriented Substation Event (GOOSE) messages to trip the preselected loads. The average time from detection of a contingency to shedding the selected loads is 50 to 70 milliseconds, including network latency, processing time, and circuit breaker operation.

The only scenario for the PMLS system not being able to maintain system stability is when all available loads are selected to shed but still do not meet the power deficit for that contingency. Because the system runs these calculations in advance of the event trigger taking place, this deficit can be seen by the operators before any actual event has occurred. This, in turn, allows corrective actions to be taken in advance so that the system can survive an event.

C. Automatic Synchronizing System Interface

As previously mentioned, the critical load buses may be isolated from the main power system and supplied by the diesel generators during certain operational scenarios, such as during a hurricane or during restoration after a complete collapse of the main power system. For these reasons, it is necessary to be able to synchronize an islanded bus back to the main power supply circuits. The advanced automatic synchronizing system included in the PMLS system provides that capability.

The generators, switchgear, and loads are located at different locations over the topside and hull of the platforms. A synchronizing operation involves different switchgear and machines in different physical locations. With limited electricians on a normal operating platform, it is very difficult to coordinate any synchronizing procedure.

The automatic synchronizing system HMI interface provides several key features, including consolidated view and control, location and access level-enabled controls, and alarm and event recording. Two types of screens are created for the system.

The first screen type provides an automatic synchronizing system overview. Critical breakers controlled by the system are typically main and tie breakers of each essential 480 V switchgear. While each GCP includes provisions for manual and automatic synchronizing of the generators to the bus, one of the systems includes the ability to synchronize across the generator breakers as a backup to the GCP.

The second screen type is a detailed automatic synchronizing screen. In these screens, the front panel of the A25A is fully mimicked.

Alarm functions of the system (e.g., close fail) are captured as active alarms on the HMI once detected. Users can then identify the current alarm state (alarm or normal) and time stamp and acknowledge the alarms if they have valid user credentials. Alarms and events are also recorded in the historical database from which users can retrieve the alarm or event history for future system diagnostics.

The PMLS engineer workstations deployed on the platform also have software installed that can automatically retrieve event reports and Sequential Events Recorder (SER) data from the A25As and store them in the local database. Selected event reports are further sent to the onshore operation center and engineering office twice a day.

IV. SYNCHRONIZING CHALLENGES

This section discusses issues that must be considered when designing a system to ensure safe breaker closing for all conditions, including synchronizing close conditions.

A. Control Interfaces

1) Situational Awareness

One of the challenges that must be addressed is the fact that the critical load buses are typically physically separated from each other to prevent a single catastrophe from affecting multiple power supply feeds to critical loads. For this reason, any switching operation may require a team of personnel in separate places, with coordination occurring via radio communications. In an emergency, the procedures have to be completed quickly and carefully.

Lack of widespread situational awareness can slow efforts to reconfigure the power supply and possibly lead to human error. A great deal of back-and-forth communications must occur so that the person in charge of the switching operation can understand exactly what the remote personnel are seeing in order to provide direction. An HMI system that can provide all remote status indication and control from a single location is helpful.

2) Multiple Interfaces

Compounding the opportunity for confusion is the fact that there are multiple control interfaces for performing most actions. Focusing on close control, each critical breaker can be closed from some or all of the following user interfaces:

1. The switchgear-mounted control handle (only functional when the breaker is in the test position).
2. The switchgear umbilical switch receptacle.
3. The PMLS HMI console.
4. The A25A front panel.
5. The GCP.

Each control interface has restrictions on what types of operations it can be used for. For example, the A25A, if configured to allow dead close, never allows the dead generator/live bus close scenario. So, if the operators are closing a tie breaker via the A25A, it will close for energizing the bus on the far side of the generator but not vice-versa.

Generally, the PMLS HMI is intended to be used as the primary control interface because it can be programmed to have all functionality and the local panel controls should only be used as backup in case the HMI is down. That way, operators get used to going to the same user interface for all operations. The GCP and A25A controls should generally only be used for operations involving synchronizing close.

B. Breaker Close Interlocks

To improve safety and continuity of service, each 480 V breaker in the power distribution system network includes extensive interlocking. The interlocks typically include the following:

1. Antiparalleling interlocks to prevent a load bus from being connected to two sources at the same time, except briefly during closed-transition load transfers.
2. Close interlocks to prevent the 13.8 kV/480 V transformers from being back fed from the diesel generators or a loop through the distribution system.
3. Synchronism check and/or dead bus permissive.

The conditions across a breaker for closing can include the following three electrical situations:

1. Dead bus on one or both sides (dead close).
2. Live/live with no slip (parallel close).
3. Live/live with slip (synchronizing close).

Each of these conditions can be addressed by a combination of interlocks and control systems.

1) Contact Logic Interlocks

Contact logic interlocks use logic circuits driven by combinations of the statuses (52a or 52b) of adjacent breakers. Dead close and parallel close scenarios can easily be taken care of by breaker status-based interlocks. For example, a main breaker may not be closed unless the transformer high-side breaker is already closed.

Antiparalleling systems address the problem using a different approach. They allow a breaker to be closed but open an operator-specified breaker when a bus has more than one source. This is used to automate closed-transition load transfers.

2) Synchronism-Check Interlocks

Synchronism-check relays with voltage elements can be used to detect dead/live conditions and can be used in place of, or to supplement, breaker status interlocks. For example, another way to interlock a main breaker to prevent backfeed is to prohibit the breaker from closing under a live bus/dead transformer condition. One problem with relying solely on voltage elements is that there is no way for the synchronism-check relay to distinguish between a true dead bus and a blown voltage transformer (VT) fuse. This can allow an out-of-synchronism close if the operator initiating the close is not careful.

Traditional synchronism-check relays also are not optimal for supervising the close command in the situation where a synchronizing close is required. These relays check that the angle is inside a ± angle window and stays there for a time delay. The angle window and time delay are a surrogate for measuring slip. The time criteria of such a relay would be set using (1).

$$25_{TD}\,\text{sec} = \left(25_{ANG}{}^{\circ} - \text{ADVANG}_{MAX}{}^{\circ}\right)\left(\frac{\text{cyc}}{360^{\circ}}\right)\left(\frac{\text{sec}}{\text{SLIP}_{MAX}\text{cyc}}\right) \qquad (1)$$

where:

25_{TD} is the synchronism-check time-delay setting.

25_{ANG} is the synchronism-check angle setting.

ADVANG_{MAX} is the ADVANG at SLIP_{MAX}.

SLIP_{MAX} is the allowable slip in Hz.

The ADVANG_{MAX} is calculated per (2), which is discussed in the next subsection. For such a synchronism-check relay, the time-delay setting must accommodate the advanced angle. For example, using a 10-degree angle window, a 0.100 Hz (36 degrees per second) SLIP_{MAX}, and a mechanism delay of 5 cycles, the ADVANG_{MAX} would be 3.0 degrees. The setting 25_{TD} would be less than 0.19 seconds to allow the synchronism-check relay to close its contacts before 3.0 degrees in advance of 0 degrees at SLIP_{MAX}. If the actual slip is less than $SLIP_{MAX}$, the synchronism-check relay will close its permissive contact well in advance of the close command from the operator or the automatic synchronizer.

The problem with this type of synchronism-check relay is that it can cause a late close. For example, if the delay is set to 0.19 seconds per the previous example and the operator has misjudged and initiated the close with slip at a slightly fast 0.125 Hz (45 degrees per second), the close coil would be energized at 8.55 degrees past 0 degrees (because the operator's hand is still on the control switch). The breaker main contacts would make at 12.3 degrees past 0 degrees because the generator would advance 3.75 degrees during the 5-cycle mechanism delay at 0.125 Hz. For this reason, it is recommended to set the delay to much less than the maximum value calculated using (1) [1].

The 12.3 degrees is out of tolerance per IEEE Standards C50.12 and C50.13 for the construction of cylindrical-rotor and salient-pole synchronous generators, respectively. The standards specify that "Generators shall be designed to be fit for service without inspection or repair after synchronizing that is within the limits listed…" The limit for angle difference for both types of generators is ±10 degrees [2] [3].

Modern microprocessor-based synchronism-check elements directly measure slip and provide a permissive with no time delay if the slip is within the allowed setting. Many of these synchronism-check elements also will provide slip-compensated, advanced angle close similar to an automatic synchronizer to assert the permissive at the precise time to close at zero degrees angle difference.

C. Synchronizing Close

To ensure safe closure during dead bus or parallel close conditions, we use interlocks, antiparalleling, and synchronism-check elements. For situations where two islanded power sources must be connected together, a synchronizing system is required. Synchronizing systems can be either manual or automatic [1].

1) Manual Synchronizing System

A manual synchronizing system relies on a human operator to determine the optimal time to close the breaker. The manual synchronizing system must include tools for the operator to visualize the following three parameters that must be checked before a breaker can be closed:

1. Voltage difference.
2. Slip (frequency difference).
3. Angle difference.

Visualization is usually provided by a synchronizing panel that includes a synchroscope to indicate the angle difference, speed, and direction of slip; voltage meters to discern the voltage difference; and synchronizing lights that provide a composite measurement of all three parameters.

The manual synchronizing system may include synchronism-check relays to prevent the operator from causing a faulty synchronization. As discussed in the previous subsection, a traditional synchronism-check relay cannot ensure a good synchronization. It is mainly there to prevent a bad synchronization.

The manual synchronizing system must also include controls to adjust the generator voltage and frequency in order to bring these parameters into the synchronism acceptance range so that the breaker can be closed once the two systems come in phase.

2) Automatic Synchronizing System

An automatic synchronizing system measures the incoming (generator) and running (bus or system) voltages, directly measures the slip and voltage difference, and checks them against the synchronizing acceptance band.

The heart of the automatic synchronizer is the slip-compensated advanced angle feature. The user measures the breaker closing time during commissioning and enters that as a setting in the control. The automatic synchronizer then calculates the advanced angle per (2), using the measured slip.

$$ADVANG° = \left(\frac{(SLIP)cyc}{sec}\right)\left(\frac{sec}{60\ cyc}\right)\left(\frac{360°}{cyc}\right)\left((TCLS)cyc\right) \quad (2)$$

where:

ADVANG is the advanced close angle.

TCLS is the circuit breaker close mechanism delay.

At the angle calculated using (2), the breaker close coil is energized and the breaker main contacts will close at exactly zero degrees. The main advantage of an automatic synchronizer over an operator is that the device can more consistently close the breaker at the precise correct moment.

An automatic synchronizer also includes generator control functions for frequency and voltage matching using a set of four output contacts to raise and lower frequency and voltage.

D. Generator Control Panel

The GCP supplied with the generator system typically includes both manual and automatic capabilities to bring the generator onto the bus. With additional synchronizing switch circuits, these controls can be extended to select breakers other than the generator breaker to synchronize a main or tie breaker. However, for more complex power distribution systems, extending the GCP controls to achieve this becomes prohibitively complex.

E. Advanced Automatic Synchronizing System

For these two platforms, an advanced automatic synchronizing system using an A25A device is included. The A25A is built on a hardware platform that has six isolated single-phase voltage inputs. One A25A is provided for each diesel generator and interfaced to the PMLS HMI. This device is used to synchronize the generator island to adjacent power system circuits or buses.

The operator can locally select the breaker to be synchronized by pushbuttons on the front panel of the control. Fig. 1 shows an example of the local front panel layout of one of the A25A devices. The A25A then selects the appropriate VT signals and settings for the selected breaker and begins checking the close conditions to determine if the situation is a dead bus close, parallel close, or synchronizing close. If one of the allowed close permissive conditions is satisfied, the operator gets a close permissive indication.

The operator can then initiate breaker closing. The A25A will either close the breaker immediately for a dead close or parallel close or initiate the matching process for a synchronizing close. As indicated in Section III, Subsection C, the operator can also perform all of these control functions from the PMLS HMI.

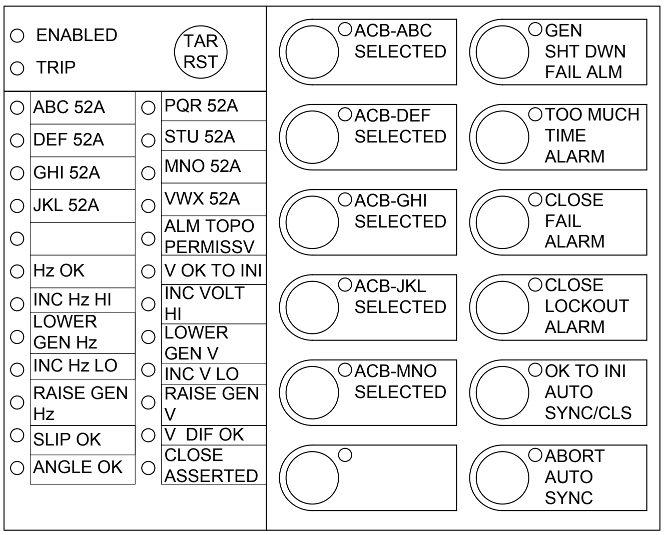

Fig. 1 Example: Platform 2, Hurricane A25A Local Controls

F. Frequency Tracking

The A25A has the ability to switch between two master frequency tracking voltage inputs. Frequency tracking is used to measure the frequency of the generator and to adjust the sampling frequency to maintain accuracy of the voltage magnitude and angle measurements.

For Platform 2, the A25A was not required to synchronize the generator to the bus. In this case, the frequency tracking input did not need to be switched and was fixed to monitor the bus voltage that the generator connected to.

For Platform 1, the A25A was required to back up the GCP to synchronize the generator to the bus. To meet this requirement, the frequency tracking input is switched to the generator VT when the generator breaker is selected and switched to the bus VT for all other scenarios.

G. Topology Permissive Alarm

The topology permissive function ensures that the power system is configured appropriately to allow the A25A to close the breaker. The topology permissive logic has two components: a continuity permissive and an interlock permissive. If an operator selects a breaker for closing under inappropriate conditions, the topology permissive alarm asserts to alert the operator. This function was not required for Platform 1 because it was always possible to directly monitor the VTs on each side of the breaker to be closed.

1) Connectivity Permissive

The connectivity permissive ensures that the voltage signals being monitored are representative of the voltage on either side of the breaker selected for close. In some cases, there are a number of breakers between the incoming (generator or generator bus) VT and the running (system or bus) VT. The continuity permissive monitors both the breaker status and the truck operated contact (TOC) and will not allow closing if any breaker in the connectivity string between the generator to be synchronized and the breaker to be closed is either open or in the test position.

2) Interlock Permissive

The interlock permissive ensures that, when the selected breaker is closed, a main and tie interlock is not violated. Otherwise, it will result in immediately tripping the just closed breaker. This is discussed in more detail in Section VI, Subsection B.

H. Frequency and Voltage Checks

The generator and bus voltage and frequency must be within user-settable healthy ranges before a close is allowed. In the case where dead bus closing is to be done via the A25A, the generator-side voltage and frequency must be within the healthy ranges and the running side must be dead.

For dead bus conditions, an operator dead bus permissive control must also be enabled. This is to ensure that the operator intends to close the breaker to energize a dead bus and that the A25A is not reading a dead bus due to a blown VT fuse.

Once a synchronizing close is in process, the INITIATE AUTO SYNC/CLOSE CB light-emitting diode (LED) blinks to indicate that frequency and voltage matching are taking place and that the A25A is waiting for the generator voltage to come into phase to initiate the close command. For a synchronizing close to take place, the slip and voltage difference must be in the synchronizing acceptance band. The statuses of these parameters are indicated by LEDs on the front of the control and the PMLS HMI.

I. Close Success/Fail Monitoring

Once initiated, the close process will continue until it ends in one of the following six ways:

1. The operator deselects the breaker.
2. The operator aborts the process.
3. The too-much-time timer expires (too-much-time alarm).
4. The A25A issues a close command and the breaker fails to close (close fail alarm).
5. The breaker closes but soon opens again (close lockout alarm).
6. The breaker remains closed for the duration of the close lockout timer (successful close).

V. PLATFORM 1 SYNCHRONIZING SYSTEM

Development of the automatic synchronizing system for Platform 1 started with the core A25A device and was customized to meet the requirements for that application. The topologies for this system are much less complex than for Platform 2, with no intermediate breakers between the generator and the breaker to be closed. However, this system was actually more complex because the A25A was pressed into service to provide a synchronism check for manual closing in addition to doing synchronizing close. Fig. 2 illustrates the input and output configurations for the black-start/hurricane generator A25A.

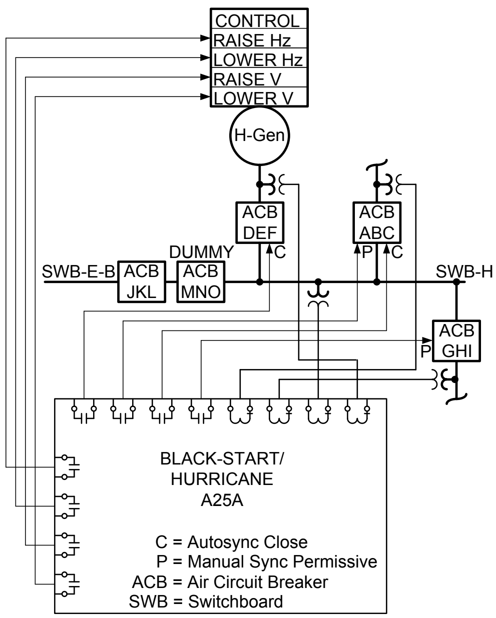

Fig. 2 Platform 1 Black-Start/Hurricane Generator A25A

Fig. 3 and Fig. 4 show the input, output, and front-panel configuration of the emergency generator A25A. Inspection of these figures reveals that there is no need for connectivity permissive logic. The A25A switches frequency tracking from the generator VT to the bus VT when not synchronizing the generator. The breakers with a C next to them are controlled by the A25A. The breakers with a P next to them include manual synchronism-check supervision.

The synchronizing system for Platform 1 backs up synchronizing close from the GCP. The operator can use either means to synchronize the generators to the bus.

A. Manual Close Permissive

To manually close a breaker that includes a synchronism-check permissive from the A25A, the operator must install the umbilical switch or select the breaker in the HMI. The operator then must go to the A25A and select the breaker he or she intends to close and enable manual mode. See Fig. 4 for these controls. If an appropriate manual close permissive condition is measured, the MAN SYNC CHK ASSERTED LED provides indication. The operator can then close the breaker to complete the operation.

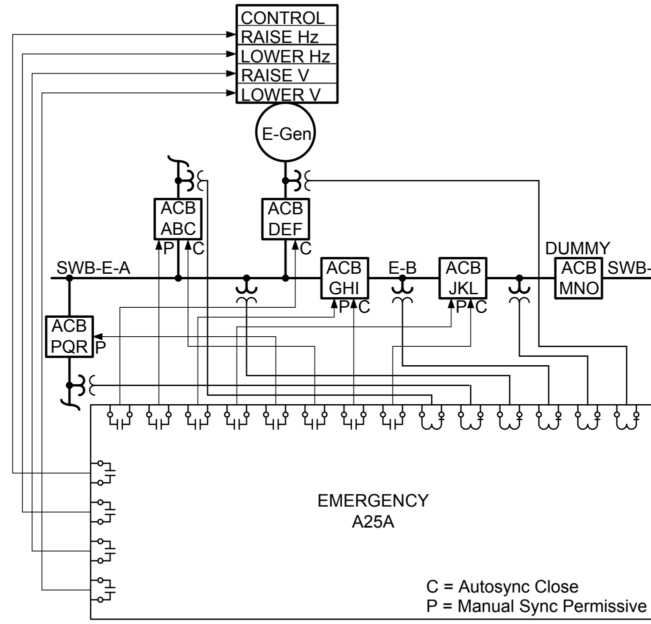

Fig. 3 Platform 1 Emergency Generator A25A

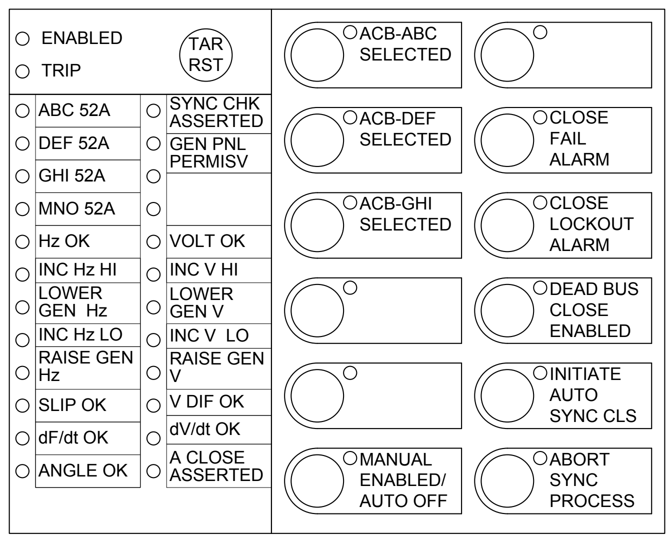

Fig. 4 Platform 1 Hurricane A25A Local Controls

Using the PMLS HMI greatly streamlines this process by automatically bringing up the A25A control screen when it is necessary to use it.

B. Dead Close Permissive

As mentioned earlier, the automatic synchronizer cannot distinguish between a dead bus and a blown VT fuse. Loss-of-potential (LOP) logic in microprocessor relays relies on symmetrical components to detect a blown fuse. Normally, these functions look for an unbalance in voltage without an accompanying unbalance in current. The A25A only monitors single-phase voltage and does not monitor current, so LOP logic is not possible.

For this reason, an automatic synchronizer or synchronism-check relay for generator applications includes an operator dead bus close enable. The A25A will blink the DEAD BUS CLOSE ENABLED pushbutton if the operator has selected a breaker for either manual or automatic synchronizing and it detects that the bus is dead. This calls attention to the fact that the operator must enable dead bus close if that is what he or she is doing or stop the switching operation and investigate why the A25A finds an unexpected dead bus condition.

VI. PLATFORM 2 SYNCHRONIZING SYSTEM

The automatic synchronizing system for Platform 2 also started with the core A25A device and was customized to meet the requirements for that application. The following is a list of customizations for this application:

1. No A25A dead close logic.
2. Generator shutdown command.
3. Topology permissive logic.
4. Hurricane mode.

Fig. 5 and Fig. 6 show the configuration of the hurricane and emergency generator automatic synchronizing systems. The status of each of the breakers shown is monitored for the topology permissive logic. The breakers with a C next to them are controlled by the A25A.

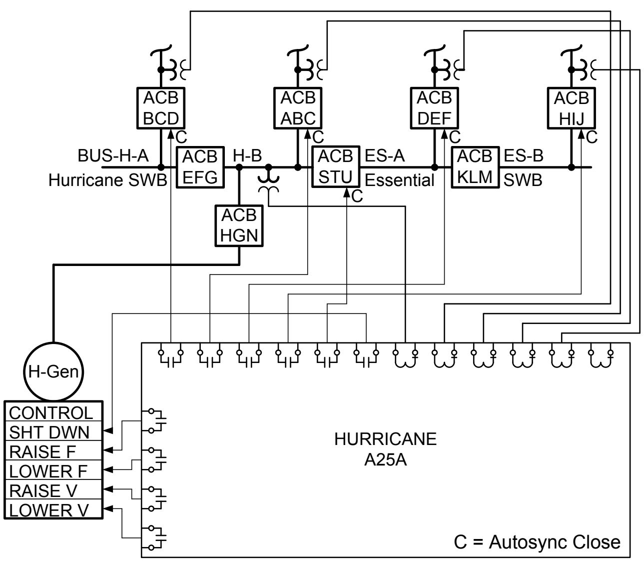

Fig. 5 Platform 1 Hurricane Generator A25A

A. A25A Dead Close Logic Removed

The breaker status logic interlocks were designed to allow any switching operation to energize a dead bus from a source. Thus, no dead bus close logic was required to be implemented in the A25A device.

B. Generator Shutdown Command

Because the A25A device is used only for synchronizing close scenarios to transfer the islanded load bus being served by the generator to the normal power, the control includes provision to command the GCP to unload the generator, open the generator breaker, and go into its cooldown cycle. The generator shutdown process is monitored and if the generator breaker fails to open, the breaker that was just closed opens again to prevent prolonged operation with two parallel sources feeding the bus. Fig. 1 in Section IV shows the alarm indication.

C. Topology Permissive

As previously mentioned, when there are intermediate breakers between the VT signals being monitored, a continuity permissive is included. For example, examination of Fig. 6 shows that before the emergency generator can be synchronized back to the main generators via Breaker DEF, the control must check to ensure that Breakers VWX, GHI, and PQR are closed and not in the test position.

This hurricane A25A also includes an interlock permissive to ensure that the hurricane generator is not already connected to the main generators via another main breaker before the breaker can be closed.

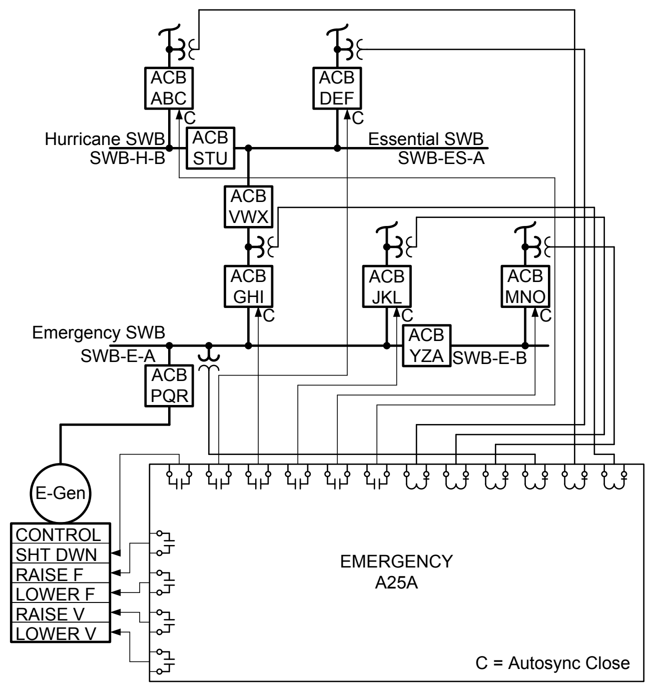

Fig. 6 Platform 2 Emergency Generator A25A

D. Hurricane Mode

The emergency A25A includes a function that allows the emergency generator to be synchronized to the hurricane generator via Breaker GHI to transfer loads from the emergency generator to the hurricane generator. This function temporarily defeats the breaker status interlock logic that trips breaker GHI to ensure that the two generators cannot be operated in parallel.

The A25A includes a control to assert hurricane mode after Breaker GHI is selected. This opens a contact in the interlock trip circuit so that it allows Breaker GHI to be closed via A25A. Once close success has been detected as described in Section IV, Subsection I, the generator shutdown command is asserted to open the emergency generator main breaker. If the shutdown process fails, the interlock defeat contact is closed, tripping Breaker GHI to prevent prolonged paralleling of the two diesel generators.

VII. CONCLUSIONS

Small islanded power systems such as those found on offshore platforms are fragile; yet, they must operate reliably for economy and safety for personnel and the environment. These systems include combustion turbine generators for main process power requirements and diesel generators for standby supply to essential and emergency load buses. These diesel generators can also be used to restart the main generation in the event of a power system collapse. A high-speed, contingency-based load-shedding system is the best way to prevent blackouts on sudden loss of generation in these small islanded power systems.

The power distribution systems on these offshore platforms have built-in redundancy with multiple circuits to supply critical loads for fault tolerance and operating flexibility. A system to easily and safely synchronize islanded buses via many possible synchronization points can revolutionize the operational flexibility and therefore the safety and reliability of the power system.

The two platforms use an advanced automatic synchronizer that has been customized to meet the needs of each platform. The systems are based on a well-proven advanced automatic synchronizer device that is capable of internally selecting between six single-phase VT inputs and providing automatic synchronizing functionality in addition to manual synchronism-check supervision.

VIII. REFERENCES

[1] M. J. Thompson, “Fundamentals and Advancements in Generator Synchronizing Systems,” proceedings of POWER-GEN International, Orlando, FL, December 2010.

[2] IEEE Standard C50.12-2005, IEEE Standard for Salient-Pole 50 Hz and 60 Hz Synchronous Generators and Generator/Motors for Hydraulic Turbine Applications Rated 5 MVA and Above.

[3] IEEE Standard C50.13-2005, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.

IX. VITAE

Michael J. Thompson received his BS, magna cum laude, from Bradley University in 1981 and an MBA from Eastern Illinois University in 1991. He served nearly 15 years at AMEREN. Prior to joining Schweitzer Engineering Laboratories, Inc. (SEL) in 2001, he worked at Basler Electric. He is presently a fellow engineer in SEL’s engineering services division, a senior member of the IEEE, Chairman of the Substation Protection Subcommittee of the IEEE PES Power System Relaying Committee, and a registered professional engineer. Michael has published numerous technical papers and has a number of patents associated with power system protection and control.

Allen Li received his MS in electrical and computer engineering from the University of Houston. He joined Schweitzer Engineering Laboratories, Inc. as an automation engineer located in Houston, Texas, in 2012. His focus is on electric power integration, substation automation, human-machine interfaces, cybersecurity, and commissioning of power management systems.

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Michael C. Tu received his BS, magna cum laude, and MS in electrical engineering from the University of Houston in 2006 and 2012, respectively. He worked as a Senior Electrical Engineer at Dow Chemical beginning in 2006, where he led major capital projects for power distribution and generation systems. In 2012, he joined Chevron as a Startup Electrical Engineer for the Deep Water Exploration and Production Facility. Michael currently serves as an Electrical Lead Engineer to provide construction, commissioning, and startup support for a Gulf of Mexico project. Michael is a registered professional engineer.

Iris Urdaneta received her BS in electrical engineering from Rafael Urdaneta University (Venezuela) in 1983 and earned a Certificate in Energy Management from the University of Houston in 2007. She has over 30 years of experience as a Project/Electrical Engineer. Prior to joining Chevron in Venezuela in 1996, she worked for Lagoven/PDVSA and CANTV. In 2004, she relocated to Houston to join Chevron, where she has been supporting the development of major capital projects.

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