DYNAMIC POSITIONING CONFERENCE
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LEARNINGS FROM INCIDENT AND INSIGHTS Session

LESSONS LEARNED FROM FINDINGS IN THE CBT PROJECT

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Objective

The important aspect of the power system is to ensure that it can ride through the electrical faults without affecting the ships or rig's worst case failure design intent and its ride through capability. This is verified by performing actual live tests.

Normally, the following tests are performed to prove ride through capability:

- A ride-through capability test (simulating short circuit)
- A live short-circuit test,

During process of DP FMEA analysis on one (1) MODU, Mobile Offshore Drilling Unit, where ABB delivered a high voltage power system, a combination of the following failures was identified as a relevant failure mode:

- A single failure: short-circuit on busbars of one (1) of the high voltage switchboards,
- A hidden failure: AVR's boosting circuit of a generator outside a faulty zone is affected by a hidden failure, does not act on demand and the subjected generator does not deliver assisted boost short-circuit current to the fault location through bus-tie breakers.

This paper considers the process performed by the involved parties post-delivery, as the official documentation was approved prior to DP trials, and the assumed identified scenario that in case of a failure of the AVR boost function, the generated short circuit would not be efficient to trip the applicable breaker.

Abbreviations

Term	Description
AVR	Automatic Voltage Regulator
CBT	Closed Bus Tested
CT	Current transformer
DP	Dynamic Positioning
EF	Earth fault
FMEA	Failure Mode and Effect Analysis
GOOSE	Generic Object-Oriented Substation Event
HV	High voltage
IAS	Integrated Automation System
In	Nominal current
MV	Medium voltage
NO	Normally open
NC	Normally closed
PVID	Port VLAN ID
PMS	Power Management System
RED615	ABB Relion RED615 protection relay
REF615	ABB Relion REF615 protection relay
REG630	ABB Relion REG630 protection relay
REX640	ABB Relion REX640 protection relay
RDS	ABB Remote Diagnostic System
RMS	Root Mean Square
SC	Short circuit
SWBD	Switchboard
VLAN	Virtual Local Area Network
VT	Voltage transformer
WSOG	Well Specific Operating Guidelines

Related documents

Ref #	Document Kind, Title	Document Id.
D1	GUIDELINES FOR VESSELS AND UNITS WITH DYNAMIC POSITIONING (DP) SYSTEMS	IMO MSC.1/CIRC.1580
D2	FAILURE MODE AND EFFECT ANALYSIS (FMEA) OF REDUNDANT SYSTEMS	DNV-RP-D102
D3	DYNAMIC POSITIONING VESSEL DESIGN PHILOSOPHY GUIDELINES	DNVGL-RP-E306
D4	REDUNDANT DYNAMIC POSITIONING SYSTEMS WITH CLOSED BUS-TIES	DNVGL-RP-0591
D5	GUIDELINES FOR THE DESIGN AND OPERATION OF DYNAMICALLY POSITIONED VESSELS	IMCA M 103
D6	A GUIDE TO DP ELECTRICAL POWER AND CONTROL SYSTEMS	IMCA M 206
D7	OFFSHORE VESSEL HIGH VOLTAGE SAFETY	IMCA M 217
D8	A METHOD FOR PROVING THE FAULT RIDE-THROUGH CAPABILITY OF DP VESSEL WITH HV POWER PLANT	MTS TECHOP_ODP_09(D)
D9	FMEA TESTING	MTS TECHOP_ODP_01(D)

Case study description, Introduction and hypothesis

During process of DP FMEA analysis on one (1) of the semi-submersible drilling rigs, where ABB delivered a high voltage power system, a combination of the following failures was identified as a relevant failure mode:

- A single failure: short-circuit on busbars of one (1) of the high voltage switchboards,
- A hidden failure: AVR's boosting circuit of a generator outside a faulty zone is affected by a hidden failure, does not act on demand and the subjected generator does not deliver assisted boost short-circuit current to the fault location through bus-tie breakers.

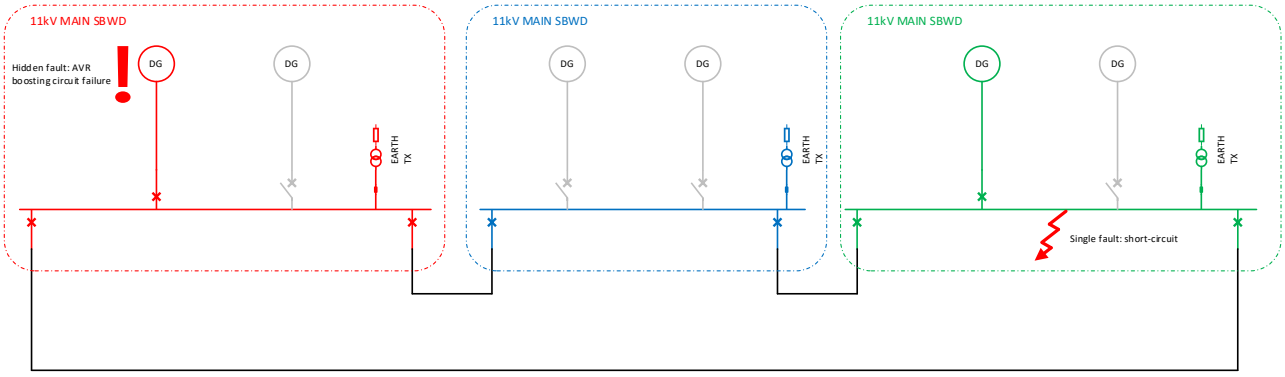

Figure 1 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical drillship power plant, Closed Ring configuration, two (2) generators online

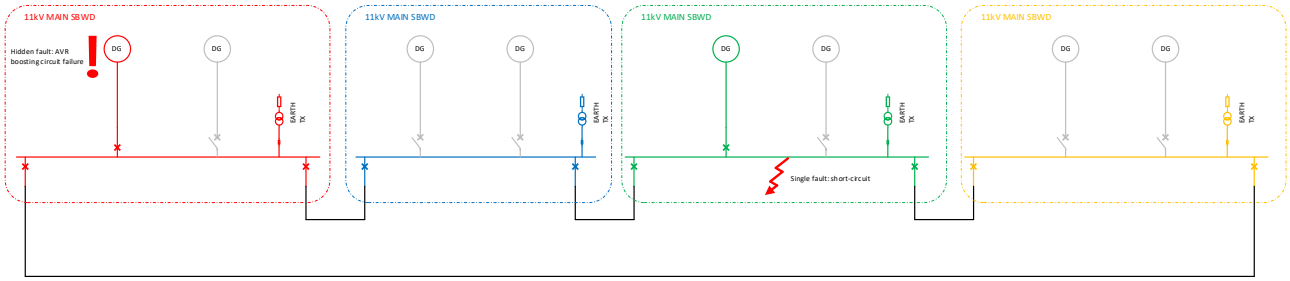

Figure 2 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical semi-submersible drilling rig power plant, Closed Ring configuration, two (2) generators online

The hypothesis was that a generator with a faulty boosting circuit (Figure 1 or Figure 2, red generator) would not be able to deliver sufficient/any short-circuit current. This issue is valid especially for Closed Ring power plants with minimum two (2) generators online. During a short-circuit on HV SWBD with a generator connected (Figure 1 or Figure 2, green 11kV MAIN SWBD busbars), there would be just one (1) generator (outside the faulty zone i.e. Figure 1 or Figure 2, red generator) contributing to fault current through bus-tie breakers. However, it is assumed that this particular generator could be the one with a hidden failure of its AVR boosting circuit. Thus, it would not contribute to the flow of sufficient short-circuit current through bus-tie breakers.

In ABB Closed Ring power plants, the setting of directional short-circuit protections in bus-tie breakers is dynamically changing:

- During the normal operation (voltage above a setpoint, typically >50% of Un, depending on the project), the directional short-circuit protections are set up with relatively high setpoint, circa 1000A (depending on the project), to allow for undisturbed power flow between HV SWBDs.
- During a short-circuit fault which is associated with a voltage dip (voltage below a setpoint, typically <50% of Un, depending on the project), the directional short-circuit protections instantaneously lower their setpoints down to circa 125A (depending on the project) to allow for pickup of protective functions and blocked-based protections to act.

It was considered that a hidden fault of a generator (Figure 1 or Figure 2, red generator) would indispose this generator from contributing to the short-circuit current through bus-tie breakers. As a result in such scenario, the 11kV MAIN SWBD affected by a short-circuit (Figure 1 or Figure 2, green 11kV MAIN SWBD busbars) would not be isolated by the means of its bus-tie breakers (detecting REVERSE fault i.e. towards the busbars). Finally, the subjected 11kV MAIN SWBD would be isolated from the generator bay; a generator protection relay (e.g. REG630 or REX640 etc., depending on the project) usually trips bus-tie breakers with 750-800ms (depending on the project, signal sent via GOOSE and/or hardwired) before it trips itself (typically 1000ms time delay, regardless of the project).

This result was questioned for the following reasons:

- The isolation of 11kV MAIN SWBD with the short-circuit (Figure 1 or Figure 2, green 11kV MAIN SWBD busbars) would be initiated by equipment in the same fire zone as the fault. This item not raised by DP FMEA vendor, but by DNV class during meeting in DNV office held on 9th of January 2025, when a general discussion regarding boosting functionality was held. In such scenario, the short-circuit could have originate from the fire/flooding and the power plant relies on action of the protection relay (REG630, REX640, depending on the project) inside the zone affected by fire/flooding. However, ABB considers this to be outside of scope of CBT rules, as exempted by RP-0591, Ch. 2.4.
- Voltage recovery on the part of the power plant subjected to ride-through was unknown. This is because the generator with the faulty boosting circuit (Figure 1 or Figure 2, red generator) was responsible for the voltage recovery. Recovery time and its slope was unknown, as such live test had not been performed in the past.
  In case of a typical power plant design for a drillship, a generator with a faulty boosting circuit would typically be supposed to recover voltage on two (2) interconnected HV SWBDs – refer to the below Figure 3.
  In case of a typical power plant design for a semi-submersible drilling rig, this number would increase up to three (3) HV SWBDs – refer to the below Figure 4. However, it should be noted that the higher number of switchboards in the post-failure scenario does not necessarily mean harsher recovery conditions. It is generator loading in the pre-/post-failure scenario that defines how difficult or how easy it is for the remaining generator to recover the voltage on the grid.

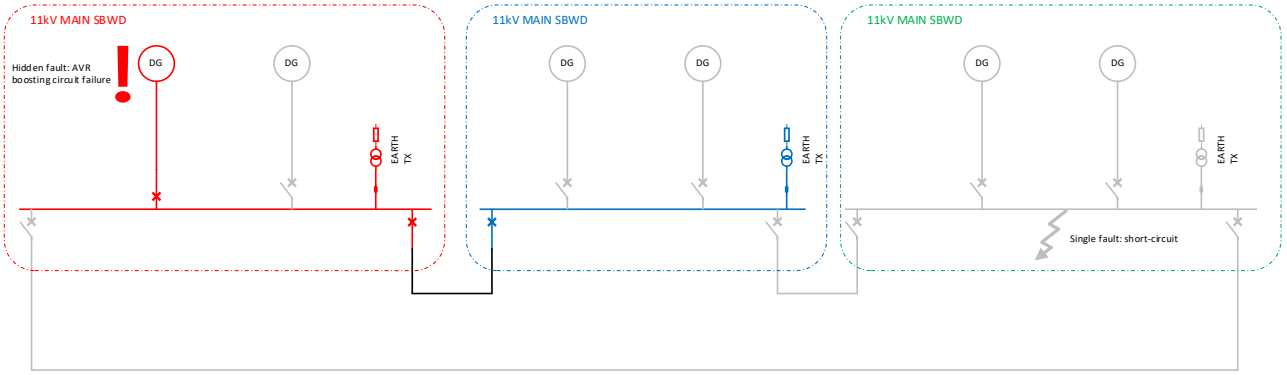

Figure 3 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical drillship power plant, Closed Ring configuration, two (2) generators online – post failure recovery

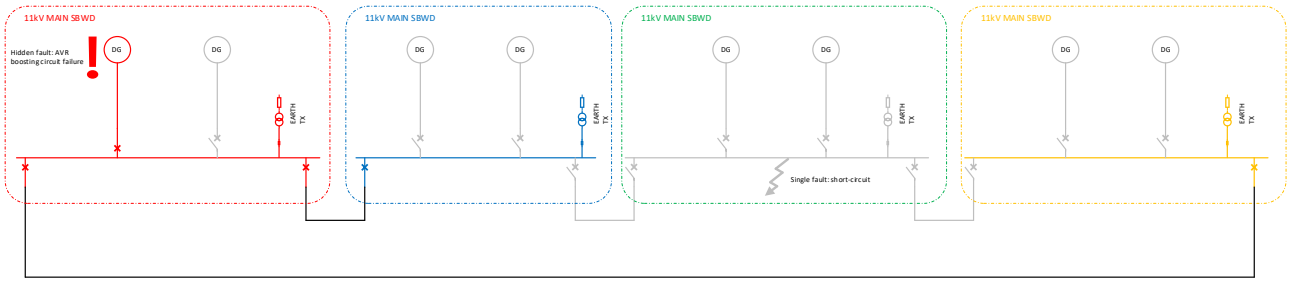

Figure 4 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical semi-submersible drilling rig power plant, Closed Ring configuration, two (2) generators online – post failure recovery

Considering other power plants setups such as Closed Ring with three (3) generators online, the combination of these single faults and hidden faults is not relevant. This is because it is considered that there is always at least one (1) generator outside the faulty zone with a healthy boosting circuit, assuming the power plant has been configured according to a well-written vessel-specific DP setup manual.

Note:

An assumption is made that the third generator is not running on the same SWBD as the SWBD with fault. Well-written DP setup manual and logic of PMS standby start should generally cover for this. This assumption is outside ABB responsibility.

Refer to the below Figure 5 and Figure 6.

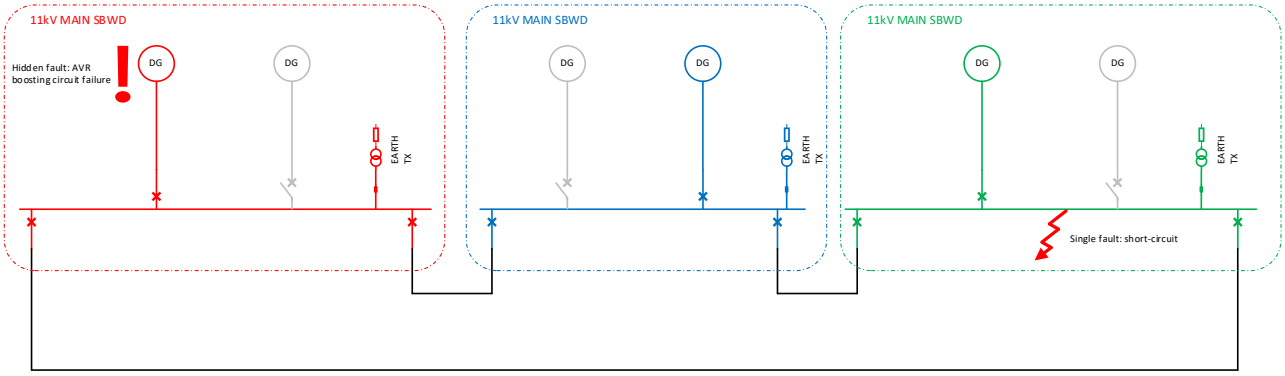

Figure 5 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical drillship power plant, Closed Ring configuration, three (3) generators online. Blue DG on blue 11kV MAIN SWBD has a healthy boosting circuit and is able to provide short-circuit current through bus-tie breakers to the green 11kV MAIN SWBD.

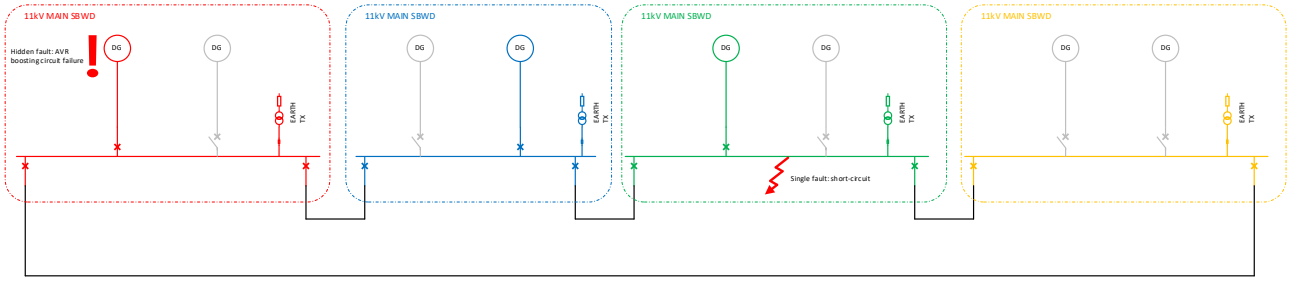

Figure 6 Exemplary power plant layout with a single fault (short-circuit) and hidden fault (AVR boosting circuit failure), a typical semi-submersible drilling rig power plant, Closed Ring configuration, three (3) generators online. Blue DG on blue 11kV MAIN SWBD has a healthy boosting circuit and is able to provide short-circuit current through bus-tie breakers to the green 11kV MAIN SWBD.

AVR boosting circuit – functionality and hidden failure definition

Functionality

The below figure presents a general AVR on-plate wiring diagram, together with boosting circuit.

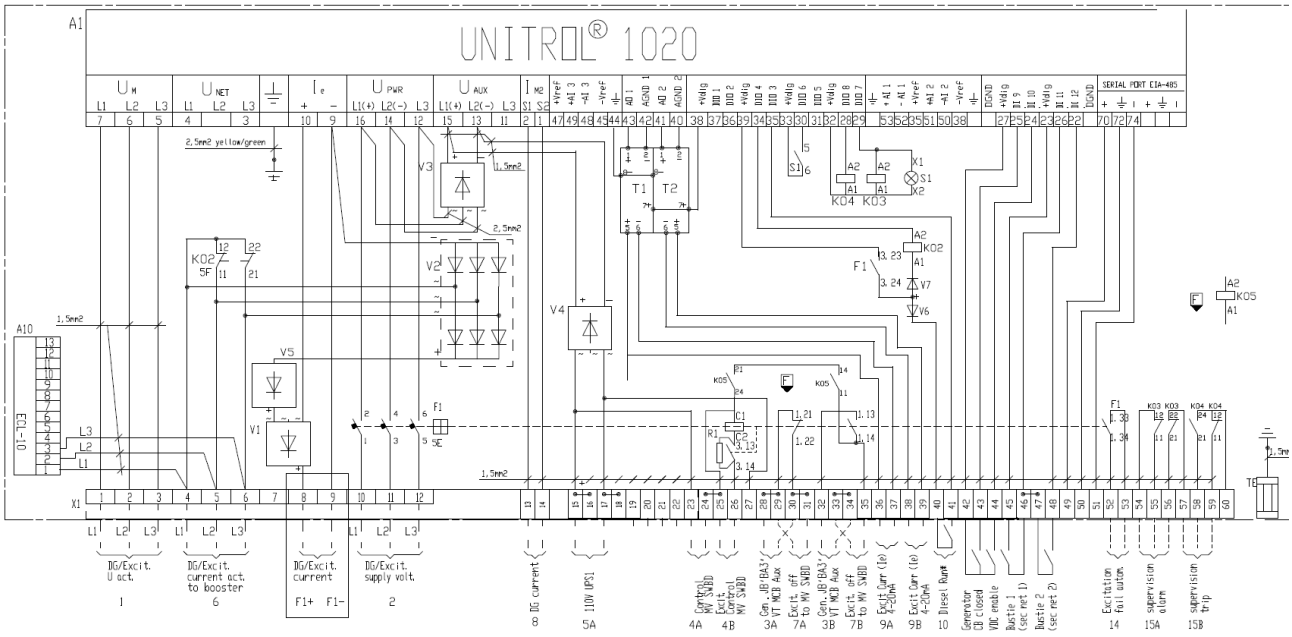

Figure 7 AVR Unitrol 1020 – typical on plate wiring diagram

In general, the boosting circuit consists of the following subcomponents:

- **A1** Unitrol 1020 AVR, which uses software-based algorithm to initiate boosting sequence (refer to the below Figure 8) by energizing its digital output A1:DIO4. 24VDC supply is provided to the control loop from A1:+Vdig output.
- **K02** contactor consisting of:
    - K02 contactor's coil with inputs K02:A1/A2.
    - K02 contactor's NC contacts K02:11/12/21/22.
- **F1** circuit breaker which auxiliary NO contacts F1:3.23/3.24 provide 24VDC power supply to **K02** contactor coil.
- **A10** ECL-10 excitation current limiter which limits the boosting current by limiting current back-fed from generator into excitation circuit.
- **V2** diode bridge that protects **A1** Unitrol 1020 AVR Exciter outputs A1:9/10.
- **V1** and **V5** diode bridges that provide excitation current to the excitation circuit from two (2) sources:
    - **A1** Unitrol 1020 AVR Exciter outputs A1:9/10 during normal operation.
    - From generator via 3CT current transformer (not presented in the above Figure 7), which ratio is adjusted so that the generator current during transient short-circuit state is safely back-fed into the excitation loop into X1:4/5/6.

- The associated cabling inside AVR cabinet and terminal strips.

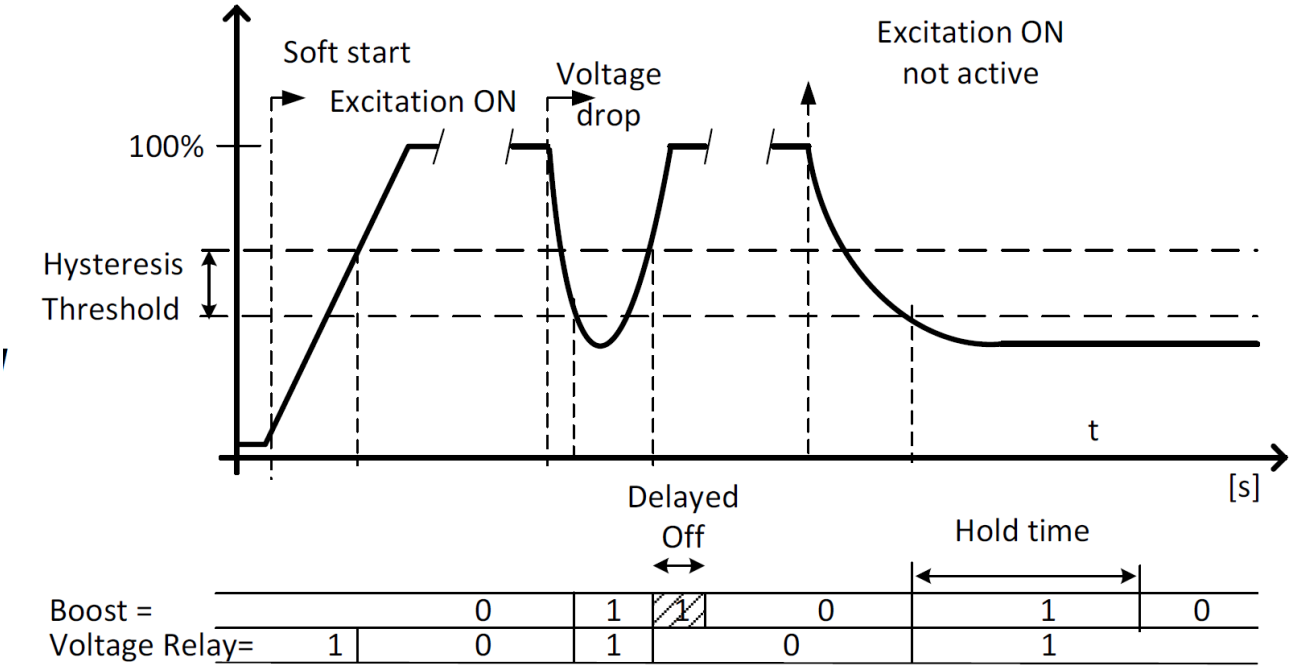

Figure 8 AVR Unitrol 1020 – Boost function

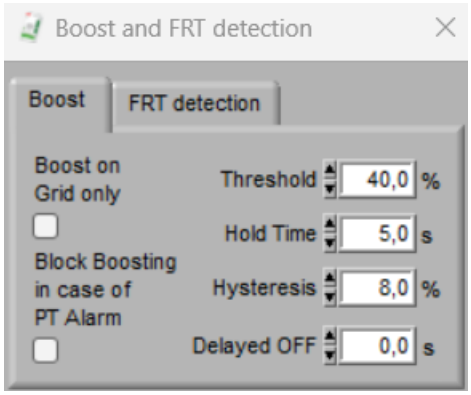

Figure 9 AVR Unitrol 1020 – typical Boost function settings

As presented in the above Figure 8 and Figure 9:

- **Threshold** [%] is a setpoint of pick-up voltage to generate boost command. Once voltage drops below the **Threshold**, A1:DIO4 is energized and goes into HIGH state. It energizes K02 contactor coil. As the result, K02:11/12/21/22 contacts open, removing short-circuiting of backfeeding loop from 3CT into excitation circuit. Finally, the generator short-circuit current is injected through 3CT back into its excitation circuit.
- **Hold Time** [s] is time for how long the boost output is active.
- **Hysteresis** [%] is a hysteresis for the reset of boost output.
- Delay time [s] is delay for turning off boosting function after exceeding **Threshold** + **Hysteresis** value.
- Check box 'Boost on Grid only' is irrelevant for marine application.
- Check box 'Block Boosting in case of PT alarm' is irrelevant for marine application.

Hidden failure definition

The definition of hidden failure was based on definition within DNV-RP-0591 as reference document for Closed Ring power plants in marine industry, especially Chapter 2.4 (general definition) and Chapter 5.2 (as far as DPS (3) and DYNPOS(AUTRO) notations are concerned).

The main argument for the hidden failure of boosting circuit was 'act-on-demand' functionality. The functionality is based on energizing the AVR output, mechanical operation of contactor, as well as on the passive components such as associated diode bridges and/or cabling. Even though the functionality is tested during live short-circuit testing, there is minimum number of generators on the grid (two (2) or three (3), depending on the owner's WSOG) during testing. The testing is repeated every five (5) years, thus there is probability of the failure remaining hidden for long time.

There are limited possibilities to monitor the boosting circuit and components involved in the boost functionality.

The following options were considered in the series of workshops between relevant stakeholders:

- Duplications of some components for increased level of redundancy. This method of dealing with hidden failures was not feasible considering very limited space on DIN rails in the existing AVR cabinets in power plants with ABB hardware.
- Additional monitoring of e.g. loop continuity. This was rejected based on the same argument as above.
- Using UPS supply, which would remain undisturbed during short-circuit within the power plant. This concept was rejected by ABB due to the following reasons:
    - Generators were tested during FAT and can deliver very specific short-circuit current decrement curve. Changing source of excitation supply from boosting circuit to UPS would lead to necessity of re-evaluation system studies for ABB power plants, including but not limited to selectivity studies, short-circuit analyses etc.
    - UPS may still fail. The main argument was that if the UPS fails, there is no excitation power and the generator is tripped, so the failure does not remain hidden.

- For most of the applications, each generator would require its own UPS, to prevent from effect of sudden trip of all generators within the same redundancy group, leading to significant loss of power in the grid.
- Space issues in some of the marine applications i.e. need for finding a space for new UPSs onboard.
- Need for significant rebuild of AVR, including isolating transformer or by-pass resistor protecting UPS battery and converter from negative effects of AVR inrush currents during start-up.
- Need for the recertification of generators, considering different engineering solution for excitation system and different decrement curve.

Description of power plant utilized for testing

The high voltage power plant subjected for testing was fitted to a drillship and consisted of three (3) 11kV Switchboards:

- 11kV MAIN SWBD No.1 (STBD)
- 11kV MAIN SWBD No.2 (CENTER)
- 11kV MAIN SWBD No.3 (PORT)

Each of the 11kV MAIN SWBDs is possible to be fed by two (2) generators and supplies electrical power to two (2) thrusters, and relevant auxiliaries associated with the respective redundancy group.

The simplified SLD of the 11kV power system is depicted in the below Figure 10.

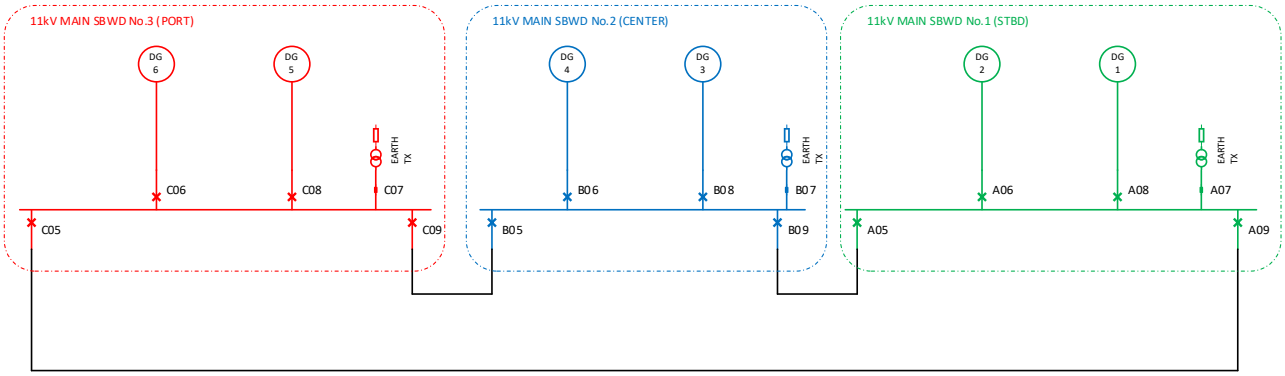

Figure 10 A simplified SLD of the 11kV power system on the drillship subjected for testing

Tests description

The power plant was configured to a Closed Ring with two (2) generators online:

- Generator No.6 at 11kV MAIN SWBD No.3 (PORT), and
- Generator No.4 at 11kV MAIN SWBD No.2 (CENTER).

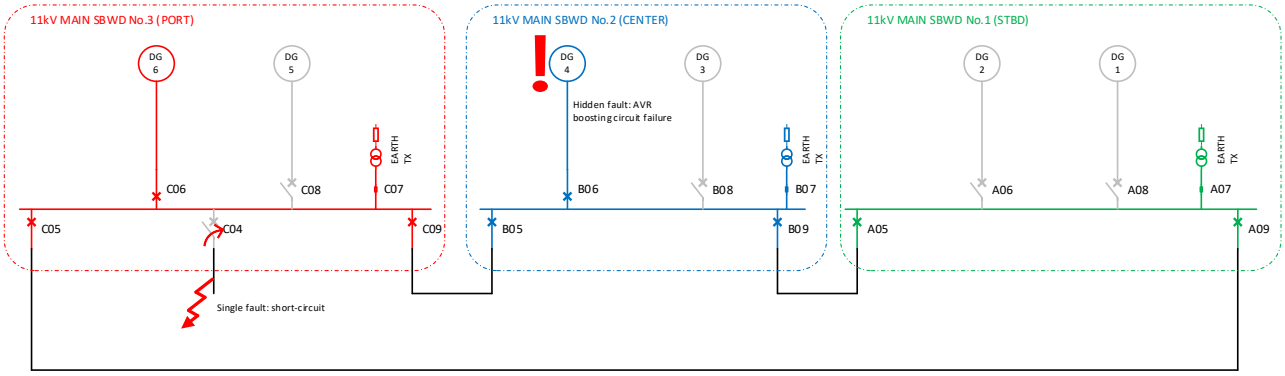

Figure 11 Faulty Boosting Circuit Test – Power plant layout used for testing of a combination of a single fault (short-circuit) at 11kV MAIN SWBD No.3 (PORT) and hidden fault (AVR boosting circuit failure at Generator No.4)

Test Results

Due to detected short-circuit, the whole 11kV MAIN SWBD No.3 (PORT) was isolated and lockout.

Unit C06 Generator No.6 was tripped. Transfer breakers C05 and C09 Master in tested 11kV MAIN SWBD No.3 (PORT) was tripped. Transfer breakers in adjacent switchboards i.e. A09 in 11kV MAIN SWBD No.1 (STBD) and B05 in 11kV MAIN SWBD No.2 (CENTER) were tripped.

In tested 11kV MAIN SWBD No.3 (PORT), both transfer units C05 and C09 Master and both units C06 Generator No.6 and unit C08 Generator No.5 were locked out for reconnection.

Two (2) out of three (3) 11kV MAIN SWBDs did ride-through the fault during voltage dip and voltage restoration process. No other units were tripped. Because the Faulty Boosting Circuit Test was performed with the drillship at quay side, the response of thrusters was not verified.

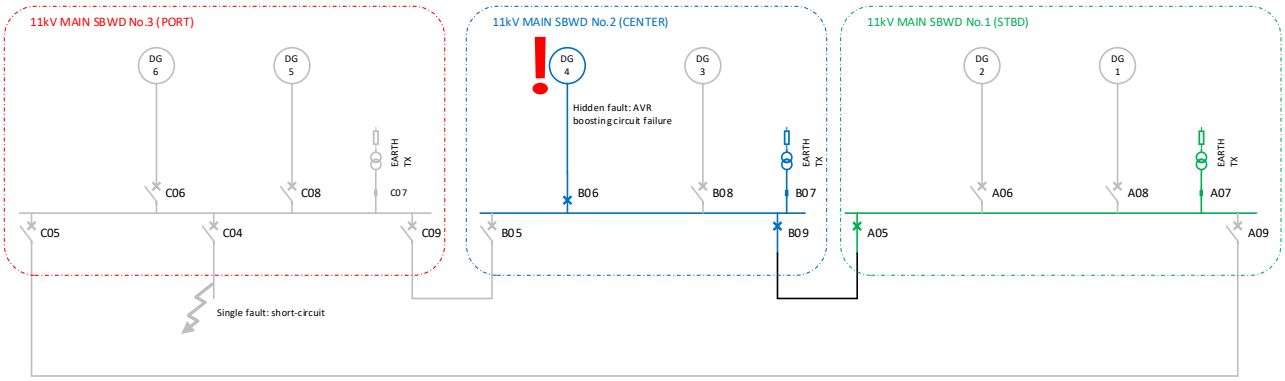

Figure 12 Faulty Boosting Circuit Test – Power plant configuration after fault clearance

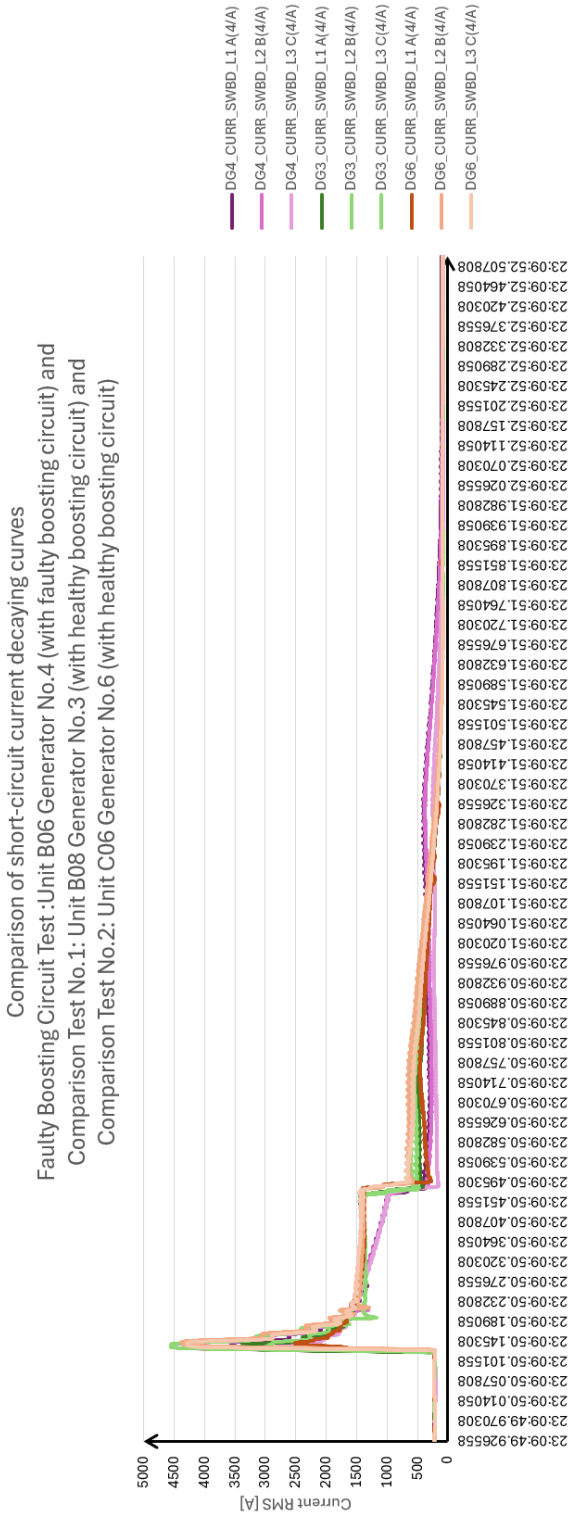
Comparison of short-circuit current decaying curves
Faulty Boosting Circuit Test :Unit B06 Generator No.4 (with faulty boosting circuit) and
Comparison Test No.1: Unit B08 Generator No.3 (with healthy boosting circuit) and
Comparison Test No.2: Unit C06 Generator No.6 (with healthy boosting circuit)
DG4_CURR_SWBD_L1 A(4/A)
DG4_CURR_SWBD_L2 B(4/A)
DG4_CURR_SWBD_L3 C(4/A)
DG3_CURR_SWBD_L1 A(4/A)
DG3_CURR_SWBD_L2 B(4/A)
DG3_CURR_SWBD_L3 C(4/A)
DG6_CURR_SWBD_L1 A(4/A)
DG6_CURR_SWBD_L2 B(4/A)
DG6_CURR_SWBD_L3 C(4/A)
Current RMS [A]
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0

Figure 13 Comparison of short-circuit current decaying curves between Faulty Boosting Circuit test, Comparison Test No.1 and Comparison Test No.2 – overall view

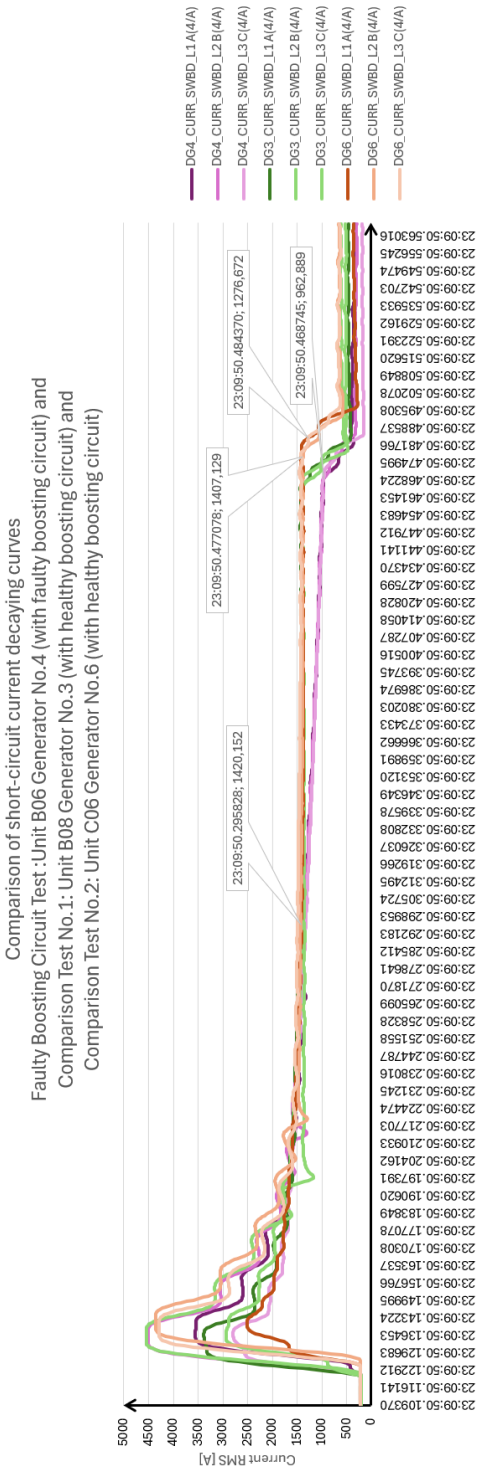

Figure 14 Comparison of short-circuit current decaying curves between Faulty Boosting Circuit test, Comparison Test No.1 and Comparison Test No.2 – zoom-in view for the RMS current values during the short-circuit. The points marked in the figure present timestamp in HH:MM:SS.ms format and current in Amps, divided with a semi-colon.

Test Setup and Comparative Analysis of AVR Boosting Circuit Performance

The test configuration used to evaluate the powerplant's AVR boosting circuit was standardized across both healthy and faulty AVR boosting circuit scenarios. This ensured consistency and reliability in comparative analysis. All tests were executed under controlled conditions, and the results were systematically recorded.

Two reference benchmarks were utilized for comparison:

- A quay-side test
- A DP FMEA sea trial

Both reference tests were conducted with fully operational AVR boosting circuits.

Observations and Findings

Analysis of the short-circuit current decay curves indicated that the generator equipped with a faulty AVR boosting circuit exhibited a more rapid current decay compared to generator with fully functional circuit.

Despite the accelerated decay, the configured protection settings and coordination mechanisms effectively prevented any mis operation.

Voltage recovery in the faulty circuit scenario was comparatively slower; however, it remained within the acceptable thresholds defined by the undervoltage protection parameters.

Conclusion

The voltage recovery process for the power system tested in the Faulty Boosting Circuit Test is noticeably slower than in the Comparison Tests No.1 and No.2. It shall be noted that even though the voltage recovery is much slower if handled by a generator with a faulty boosting circuit i.e. Generator No.4, it was still within settings of undervoltage relays for the drillship subjected for testing. The settings refer to:

- Undervoltage settings of bus-tie breakers, feeders and generators,
- Undervoltage settings of LV consumers, i.e. motor starters, and incomers and feeders.
- Undervoltage settings of thruster drives for main and backup power supplies.
- Others.

It shall be noted that the setpoint for starting of undervoltage functions (protection settings / UV relays etc.) must not be confused with the reset setpoints. The reset setpoints are usually slightly higher than start setpoints, due to hysteresis. Regardless of that, the results are still acceptable.

The generator with a faulty boosting circuit (i.e. Generator No.4) was subjected to a sudden load step. This was related to:

- Tripping of another generator with a healthy boosting circuit i.e. Generator No.6.
- Handling load of two (2) HV switchboards. Since the 11kV MAIN SWBD No.3 (PORT) was tripped, one shall not say that the generator with a faulty boosting circuit i.e. Generator No.4 took a load step from 50% to 100% of load (considering that both generators were loaded to around 50% prior to fault). At the same time, the blackout prevention systems such as event-based fast load reduction, phase back etc. reacted. Due to system dynamics, one may say there was no load at all after the fault was cleared, because of voltage dip. One may observe an increase of current on the Generator No.4 when it starts to recover the voltage, and this is related to re-energization of transformers and restart of electrical motors.

As far as the voltage recover process is concerned, there is one finding addressed. For the ABB Marine power plants operating in a Closed Ring configuration with minimum of two (2) generators online, one shall assess undervoltage settings throughout the power plant. This is related to, but not limited to:

- Undervoltage settings of bus-tie breakers, feeders and generators,
- Undervoltage settings of LV consumers, i.e. motor starters, and incomers and feeders.
- Undervoltage settings of thruster drives for main and backup power supplies.
- Others, as required.

Generally, as per a good practice considering class rules of -15/+20% of voltage variation (ref. DNV Rules for Classification of Ships, Pt.4 Ch.8 Sec.2, 1.2.4), none of the undervoltage setpoint should be setup above 85%. The usual settings are within 70-80%, with time delay of 1.5s. Theoretically, that should mean around 74-84% of reset threshold. Time span of voltage recovery up to 85% took maximum of 1100ms in the Faulty Boosting Circuit Test, counting from the moment of short-circuit. Even though this margin seems safe, it is advised to verify project-specific settings. It is advised to perform a ride-through test with a voltage dip setting of 1500ms.