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Independent Performance Validation for Robust and Resilient DP Systems

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ABSTRACT

A concept called the three pegs has been adapted to guide the development of robust and resilient DP systems. The three pegs are Intent & objective, basis-of-confidence and defense-in-depth. The intent and objective is the development of a DP system capable of performing incident free DP Operations. The basis for confidence is all activities carried out to provide confidence the objective will be achieved. Defense-in-depth refers to the process of defending all the barriers developed and identified when establishing the basis-for confidence. Independent Performance Validation (IPV) is an element of both basis of confidence and defense-in-depth. IPV a data centric concept applied to the design, validation and verification of DP systems which provides a high degree of confidence that the DP system is intact and in good working order. It is a 'Principle' based approach that is objective and outcome driven. The concept of IPV is agnostic to the system design, and its provider, and can be used in many different applications. It is based on a sensor ecosystem and high-speed data logging infrastructure which enables automatic and semi-automatic test functions which detect the onset of deterioration or malfunction in active and dormant elements of the DP system. This approach reduces the need for intrusive maintenance and out-of-service time to conduct tests and trials. This paper discusses its application to 7th generation drilling units with examples of how the concept has been applied in the power and propulsion systems. The extension of this concept to other elements of the DP Control system is also discussed.

Introduction

The history of technological development is characterized by points of inflection that signify fundamental changes in some aspect of how technology is used or applied. Such points of inflection may occur for many reasons, such as changes in the regulatory regime. More often than not, they are caused by the emergence of disruptive technologies. Such disruptive technologies often begin their progress to dominance from a point well below the level of the incumbent technology in terms of quality and reliability but offer other attributes that early adopters value such as flexibility or ability to integrate with other technologies and offering cost effective solutions. Digital photography and voice over internet are obvious examples of such disruptive technologies. When introduced they provided inferior quality initially but almost completely replaced the incumbent technologies within a few short years. Today, these technologies offer equivalent or superior quality combined with many other advantages. Inflection points of such technologies are not always obvious to those involved at the time of their emergence and the incumbent technology providers may initially resist or dismiss the emerging technology pointing to its short comings. Historically, this position is reversed within a short period of time during which the incumbent providers are forced to reverse direction and embrace the new technology which may involve major restructuring of business models. Some fail to recognize the shift until it is too late causing long established businesses to disappear.

The oil and gas industry now faces such an inflection point driven by emergent technologies, new energy sources and the prolonged and brutal market conditions which prevail in the present downturn. Such conditions are often the engines of innovation as companies review their processes seeking to eradicate non-value-added activities and inefficient processes.

An example of such a shift can be found in the US Shale Oil Industry. Hydrocarbon production from Shale has undergone a transformation in response to the current market environment. Production costs have been slashed through innovative thinking and application of technology. The efficiency gains and translation into lower costs have made shale a prominent player in the energy mix and offers a challenge to the position of hydrocarbon production from deep water. The deep-water oil and gas industry grew on the back of $100/bbl. oil in an era when the focus was on Net Present Value (NPV) rather than margins. The current market environment has forced the Oil and Gas Industry to adjust to the new realities of a "lower for longer" or increasingly in a "lower for ever" oil price regime. The industry has been forced to focus on margins and as a result, there is a strong focus on costs and efficiencies. It is emphasized that the focus on cost should not result in an increase in the risk profile or exposure to process safety events. Achieving the above objectives is crucial to the long-term sustainability of production from deepwater to be part of the energy mix going forward. Managing the risks inherent in the deepwater segment in a cost-effective manner is essential. Applying the concept of Independent Performance Validation (IPV) is a key enabler of achieving this objective of managing risks in a cost effective manner.

Dynamic positioning (DP) of vessels continues to be a key enabling technology for the development of deep-water oil and gas fields. DP as a means of station keeping is also being increasingly deployed in shallower water developments due to a multitude of reasons (e.g. congested seabed architecture, ease of mobilization, availability of assets etc.). DP station keeping is also being used in application outside the oil and gas industry (e.g. wind and tidal turbine installation, fisheries etc.)

In many activities, such as drilling and diving, the potential consequences of a loss of position are high. and supplemental barriers such as blow-out preventers, emergency disconnect systems, dive control response systems and diver recovery systems are applied to limit the severity of the consequences. Notwithstanding these response measures, a very high degree of station keeping integrity is required to reduce the potential for a loss of position and to reduce the overall risk to an acceptable level. Robustness and resilience in station keeping are also highly desirable attributes in terms of reducing overall cost - in particular, by reducing exposure to non-productive time.

The terms 'robust' and 'resilient' are widely used in engineering to describe desirable attributes in system design. The concept of three pegs has been adapted to good practice in DP vessel design and operation. The three pegs are Intent & objective.

- Basis of confidence
- Defence in depth.

Intent and objective define the scope while basis of confidence encompasses all those activities that are required to demonstrate the robustness and resilience of the design. Defense in depth refers to the activities required to ensure the integrity of barriers to unacceptable outcomes. Independent Performance Validation forms a part of Basis of Confidence and 'Defense in Depth'.

In the case of fault tolerant DP systems:

- Robustness is the property of a system which can resist damage and avoid failure
- Resilience is the property of a system which can accept failure and continue to function or recover functionality quickly.

Robust and resilient DP systems have high availability and therefore low exposure to non-productive time. Robust systems can ride through severe demands or transient phenomena without damage or failure. Resilient systems can continue to operate effectively after some part of the system has failed. The ability of a fault tolerant DP system to continue to maintain position and heading after some part of the system has failed depends upon the performance of the surviving equipment and the protective functions that limit the severity of failure effects. The ability of a DP system to continue to carry out its industrial mission depends upon it retaining adequate fault tolerance after suffering a failure. The latter requires the system to be highly resilient with respect to the most probable failures which could erode its fault tolerance. Performance deterioration can remain hidden until a failure places significantly increased demands on surviving equipment. Protection systems are potential hidden failures because they lie dormant waiting to detect the onset of failure effects which trigger them.

Traditional techniques for verifying the integrity of DP systems include:

- Classification society rules and surveys during construction and in-service
- DP system FMEAs, proving trials and sea trials
- Field arrival trials
- Annual DP trials (continuous or batch)
- Planned maintenance activities
- Check lists.

All these activities are labor and time intensive. Some activities are overly reliant on the frailties of the human observer. Test methods are relatively crude and fail to fully test performance attributes, essential protective functions and detect potential hidden failures. The burden of verification potentially results in non-productive time and as a result it is not unusual to try and limit the verification scope to what can be accomplished in a reasonable time, rather than what is required to test the system fully. In addition to the above a “blind” compliance mentality has been responsible for reducing the value of some assurance activities and has unfortunately resulted in documentation that is more reflective of a ‘ticket to trade’ than an objective evaluation of effective risk management/risk mitigations. This approach has a doubly detrimental effect in so far as its not effective in reducing exposure to DP incidents and non-productive time but requires significant cost and non-productive time to execute.

The pressure to cast aside legacy thinking, inefficient practices, ineffective test methods have now reached critical levels within all stakeholders in the Oil and Gas Industry and especially in oil companies and vessel owners. For some stakeholders, this is a matter of survival not choice. This pressure has resulted in the launch of a number of initiatives. However, some initiatives are likely to continue legacy thinking and practice albeit in other forms with little tangible improvement on station keeping reliability and integrity. Those who chose this path exclude themselves from the substantial benefits to be gained from the application of affordable technology that transforms the whole verification and assurance process.

The vision for the future of DP system verification is one in which much of the verification process is undertaken, unseen, while the vessel carries out its industrial mission or transits from one location to another and with a minimum of human intervention. Observations traditionally carried out by humans are supplemented by a data centric approach which includes data analytics. Data integrity is ensured by triangulation and other methods which make it impractical to falsify results.

Some functions and features upon which fault tolerance depends lie dormant until triggered by the fault conditions they were intended to address. DP vessels, which by design have incorporated a large degree of non-critical redundancy may be able to test these functions without risk during their industrial mission. DP vessels which have incorporated the objective of reducing out-of-service time due to verification activities and reducing the cognitive burden in general, by design, can successfully limit the exposure to avoidable non-productive time.

Vessel owners rightly point to significant overlap and duplication in verification and third party assurance processes required by classification societies and charterers. These inefficiencies were tolerated in periods of high revenues but there is no need to preserve them going forward. Independent marine and DP assurance organizations came into being to address a perceived resource and competence shortfall. However, the wide variability in the skill levels of the personnel from such entities has eroded the confidence placed in the output of such assurance activities. Building trust and confidence in the process is essential if charterers' requirements are to be satisfied. Technology can and should be deployed effectively to rebuild the eroded confidence.

Many stakeholders in the verification process recognize that industry views are changing and are proposing alternatives and initiatives:

- Classification societies would like to provide remote survey and renewal processes which requires them to create new rules to allow it and redefine the way to satisfy their verification scope.
- Vessel owners want to reduce the out-of-service time burden and associated costs of attending surveyors and get more value from the process.
- The independent DP assurance organisation may need to reinvent themselves as data analysts as requests for traditional annual DP trials fade over time. Failure modes and effects analysis, as it is traditionally practiced, may be replaced by system models which form part of real-time confidence building measures.
- Statutory and regulatory bodies may need to accept new practices as equivalent to or better than established methods described in guidance.
- Charterers will want access to data that satisfies their requirements to control their own risk portfolio. -Vessel owner will seek secure methods to provide it too them.

An opportunity now exists to leverage technology to remove duplication while enhancing the benefits of the verification process. At least two Classification Societies who have a significant market share of the Oil and Gas Industry have embarked on a journey of meeting stakeholder expectations by undertaking initiatives which includes conducting workshops with industry participation in Norway and United States. These workshops have been attended by a range of stakeholders including vessel owners, oil majors and equipment vendors. One Organization's stated objective was to:

Create an improved and less invasive classification scheme for verification of DP systems by enabling the use of modern technology.'

As is often the case with disruptive technologies, the innovators are setting the pace. An interesting element of this pace setting is that the innovators and early adopters are driven by the tangible benefits from deployment of the disruptive technologies in terms of improved reliability, robustness and resilience. They recognize that regulations lag innovation and that the deployment of such technologies may not result in a reduction in the burden of surveys and trials in the near term. Having proved the concept objectively and demonstrating the benefits of a data centric approach, they are now rightfully seeking credit for demonstrating the enhanced verification of their DP systems design integrity. Credit is being sought through Additional Class Notation which allows for:

- Reduction in intrusive equipment survey and tear-down (potential to introduce problems),
- Reduced maintenance effort
- Extended and variable survey intervals
- Transition away from calendar to condition and event driven maintenance.
- Using confidence indicators to drive the verification schedule

Independent Performance Validation

- The terms verification and validation are sometimes used interchangeably but mean different things. In very general terms:
  - Validation is the process of confirming that the specification will achieve the objective.
  - Verification is the process of ensuring a system is built to, and remains within, specification.

Once the design has been validated, the process of verification becomes an ongoing process of ensuring the system is intact and performing to expectations. Revalidation can be performed periodically as knowledge improves with time and learnings from incidents.

Independent Performance Validation (IPV) is a 'Principle' based approach that is objective and outcome driven. The principle itself is agnostic to the system design or hardware configuration to which it is applied. Its practical implementation, as described in this paper, takes the form of a range of innovative design and monitoring features being used to increase confidence in the robustness and resilience of 7th generation drilling rigs [1]. Although it was developed for DP systems and drilling equipment, it is equally applicable to DP vessels carrying out other industrial missions.

In IPV, the concepts of design, validation and verification are closely linked in so far as systems are built to be verified. Adherence to the principles described in MTS DP committee design philosophy guidelines as the 'Seven Pillars' produces designs which are well suited to IPV. When the principles in the first three pillars on the left are adhered to, the reliance on the last three pillars to the right is reduced. As is the burden of proving these attributes are present.

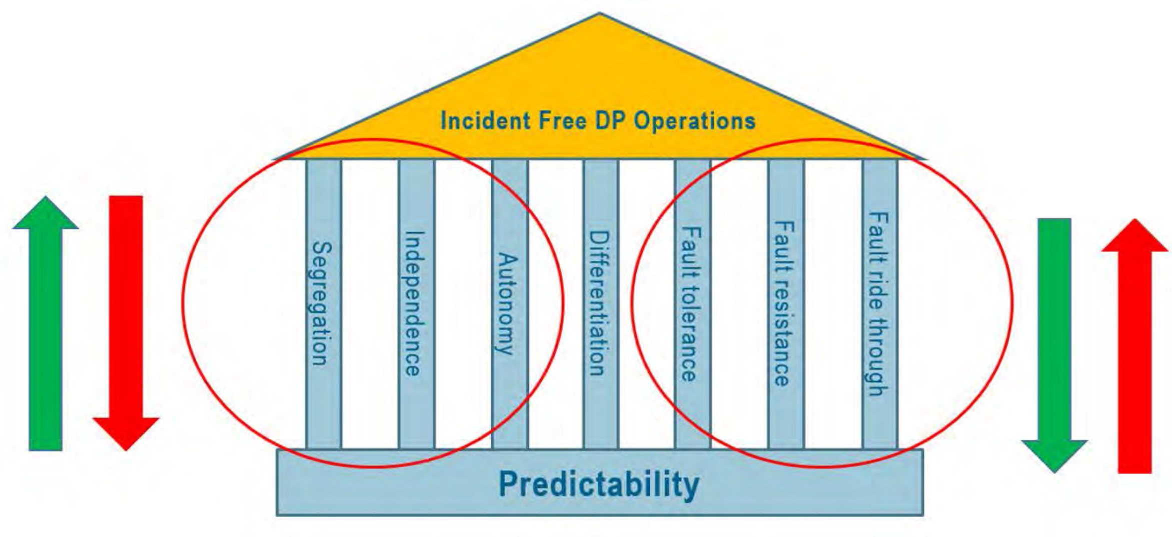

Figure 1 Desirable Attributes in DP System Design – 'Seven Pillars'

BUILT TO TEST – The ability to apply IPV is not entirely dependent on the system being designed and built for testing but it is significantly enhanced when the principles of autonomy, independence and segregation are adhered to. When these desirable attributes are present it allows the major machinery groups such as generators, thrusters and switchboards to be tested in isolation limiting the impact of testing on other parts of the DP system.

When the 'built to test' philosophy is applied, it results in a vessel with a system that is designed for efficient and effective validation and verification. It is expected to result in diminishing the reluctance to demonstrate an essential attribute or protective function by testing for fear of damaging it. Any practical limitation will be identified in advance and means to close the confidence gap will be developed in partnership with the design development.

Note: Many of the functions and features described below are useful in the commissioning stage (e.g. to reduce the tuning time of DPCS and PMS.)

TEST ON DEMAND – Equipment is designed and constructed with all the Built In Test Equipment (BITE) and other functions required to perform the testing which provides confidence in its integrity. Such test functions are designed to be easy and efficient to operate and the data presented in a manner that is easily interpreted and accessible by those who need access to it.

HEALTHY TO OPERATE – Every piece of essential equipment or system provides an indication of its current state of health and an assessment of the current level of confidence that it will remain healthy. Confidence is assessed by monitoring a range of functions and events. When confidence levels fall, the IPV process advises that activities are required to restore confidence.

DATA INFRASTRUCTURE - The backbone of IPV is an infrastructure of high speed data loggers that collect a wider variety of important data at a much higher level of resolution than traditional alarm and monitoring systems. Different data sampling rates are required for different parts of the DP system with highest rate being reserved for power systems.

IPV relies on a data centric approach. Data is the key to understanding system deterioration and malfunction rapidly and effectively and is a key component of resilience. IPV accepts that failures can and will occur but provides the means to rapidly identify problems and the remedial measures required to restore confidence for return to work.

GENETIC HARDWARE – The burden of creating the infrastructure can be eased through the use of genetic hardware. Rapid prototyping linked to automated low volume production facilities makes the creation of flexible hardware and software tailored to the specific application. The ability to embed large amounts of data storage along with a range of sensors allows equipment such as switchboards, UPSs, thruster and drilling drives to be populated with data acquisition functions within equipment that also provides other functions required for normal operation. The redundancy that is present in DP vessel systems means that there is adequate coverage for failure of the sensor packages themselves in addition to the equipment they are intended to monitor.

Examples of independent performance verification

1. Cascade waveform injection testing

The fault tolerance of DP power plant operating with closed busties is heavily reliant on a sophisticated suite of digital protective functions, within a range of devices, which must all operate in a coordinated manner to ensure predictable failure effects for all possible fault conditions. Traditionally, protective devices are tested under static conditions, on their own, against the results predicted by a coordination study. In the case of cascade injection waveform testing, all the protective functions in the switchboard can be simultaneously subjected to a stimulus that closely mimics real fault conditions. As shown in Figure 3, this stimulus is generated by a large multichannel power amplifier feeding the three-phase VT and CT inputs of the protection devices. The amplifier can be driven from two possible sources:

- Actual digital recordings of real fault conditions obtained during live testing
- Simulated fault conditions generated by a mathematical model of the power plant

Note: The model is itself validated by confirming it can accurately reproduce the live test results

The mathematical model can simulate a range of power plant configurations and fault scenarios much greater than that which can be practically tested at commissioning and FMEA proving trials. In the vessel's delivery phase, this can be used to confirm the efficacy of the protection scheme and develop a base-line against which the performance of the protection relays and circuit breakers can be compared during the vessel's life-cycle. To ease the time and cognitive burden on the users, the amplifier is connected by way of a built-in test harness which minimises the risk of disabling the switchboard by failing to reinstate it after test. The signal from the protection relay signal outputs are monitored after reinstatement to ensure all CT and VT inputs have been restored to their operating position.

The mathematical model is capable of simulating:

- Generator fuel and excitation control faults
- Broken conductors
- Short circuits and earth faults (various combinations of phases)
- Arcing faults
- Crash synchronisation
- Overload conditions
- High transient events (i.e. loss of a generator)
- System / bus resonance conditions
- Excessive harmonic distortion
- Any combination of above faults.

Built-in test equipment within the switchboard monitors and records the applied voltages and currents and the action of the circuit breakers that operate in response to the stimulus. Figure 2 Shows an example of a simple model being used to test the protection response to a governor failing to the excess fuel condition. Injecting varying frequency at constant kW into the protection system drives the generator's operating point off the model of the governor's droop line in the generator protection system initiating the expected protection response which trips the faulty generator offline.

The nature of the target protection scheme for which this particular IPV application was developed requires no interaction between the mathematical model and the switchboard. The applied fault persists until the last protection device has operated in the expected sequence. In other protection schemes, the model can interact with the protection relays in real-time to simulate the fault being cleared and the new power plant configuration is modelled after the configuration change and provided to the system.

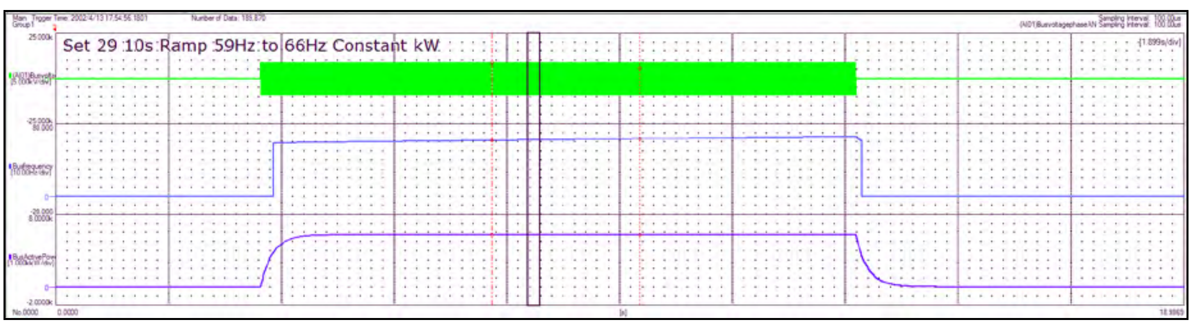

Figure 2 Simulating Governor Failure to Full Fuel

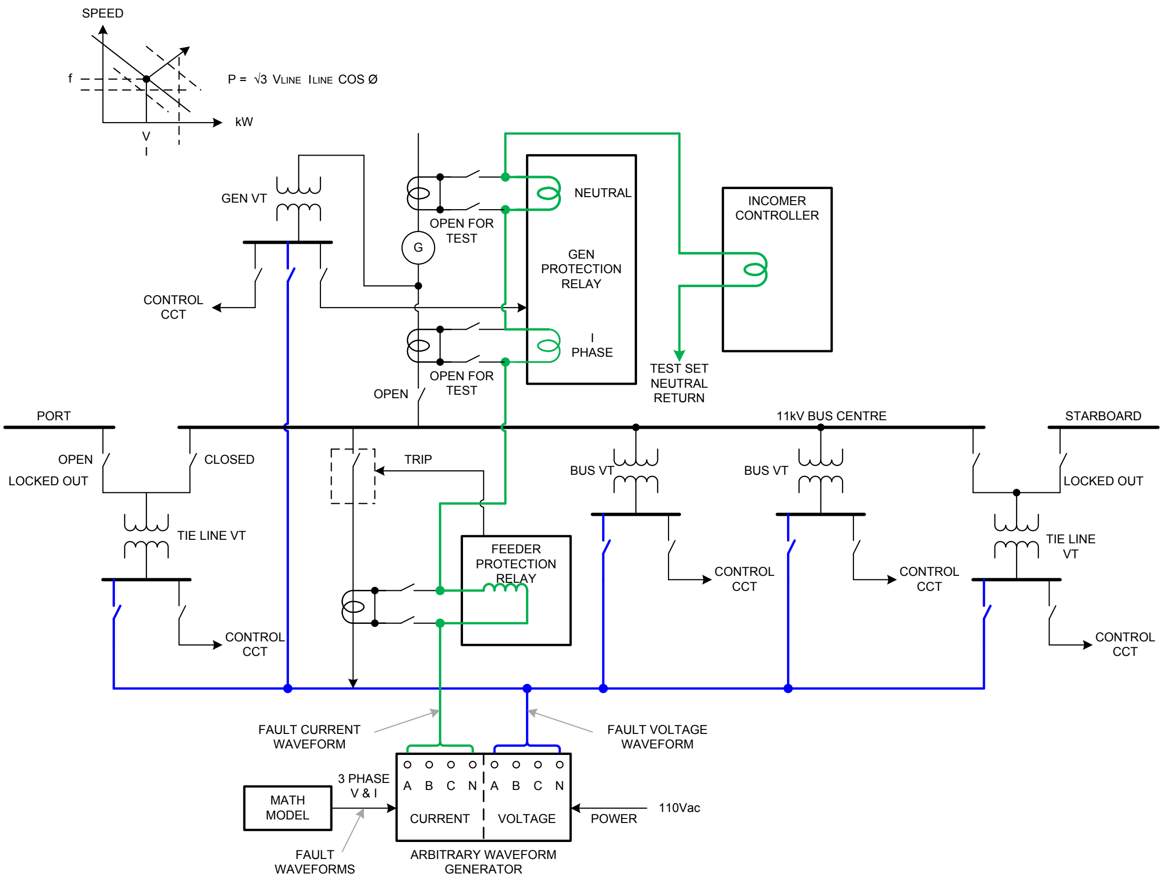

Figure 3 Interface Between Test Set and Switchboard

Figure 4 Prototype Test Arrangement Used for Proof of Concept

Figure 4 shows all the connections to the high voltage switchboard applied during the development and proof of concept phase. All test leads, current and voltage probes and oscilloscope are replaced in the fully developed version by built in test equipment and data logging functions within the switchboard itself like those shown in Figure 5. Only the waveform generator (power amplifier) and laptop computer generating the waveforms remains external.

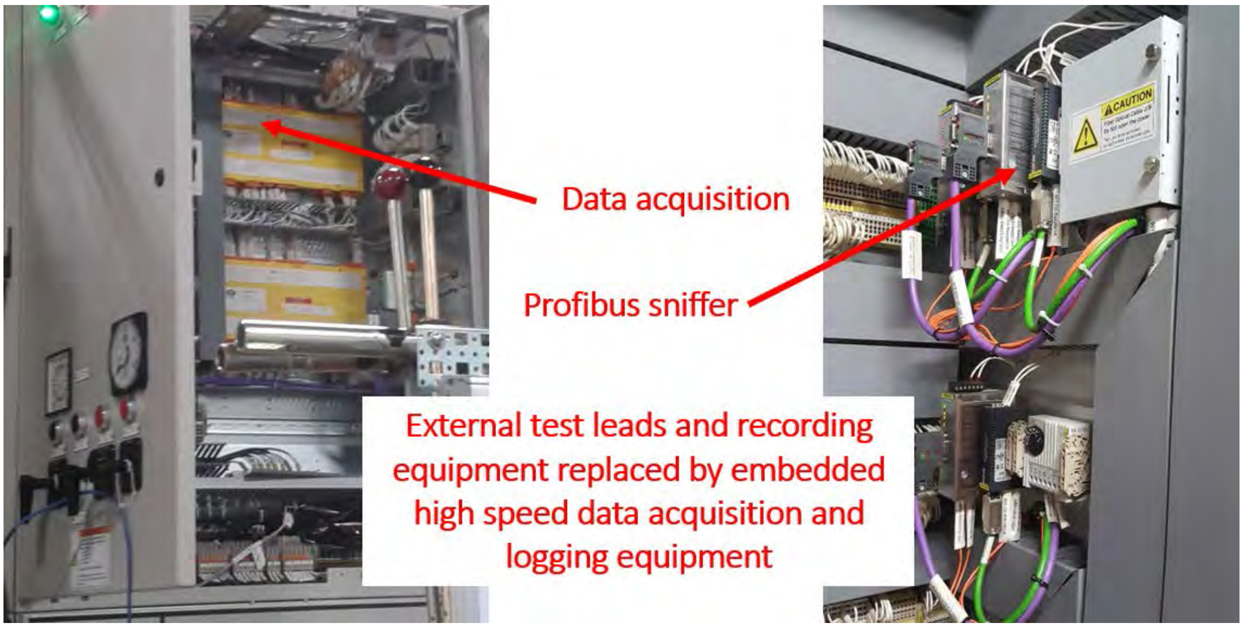

Figure 5 Production Units Benefit from Embedded Data Acquisition and Logging Functions

2. Testing engine and blackout prevention performance using DBRs

Lack of performance in DP related equipment is a potential hidden failure with the ability to defeat the redundancy concept. DP vessels operating with independent isolated power plant (busties open) are not immune to this type of failure mode and proving that all redundant elements are capable of their expected performance is part of the process of proving fault tolerance.

Generators in diesel electric power plant must be capable of accepting step loads associated with increasing demand and loss of generating capacity. Such load changes must be accepted without an unacceptable drop in bus frequency.

In modern power plant the load acceptance of the generators may be assisted by phase-back of electronically controlled loads such as drilling and thruster drives. Historically, the efficacy and stability of the power plant was tested by applying thruster load and tripping generators to create step loads. Such methods provide some insight into generators and load shedding system performance but creating load using thrusters in bias mode lacks precision and it can be difficult to arrange test conditions that allow the correct operation of various layers of load shedding to be confirmed. A much more precise step load can be created by turning on and off the Dynamic Braking Resistors (DBR) used to dissipate excess regenerated power from the drilling drives. In modern 7th generation designs these can be used to test the generators and turned on and off instantly. Loads can be created in 1MW steps up to the maximum available which can be of the order of 15MW.

This facility allows a much more controlled step load / unload to be created and is particularly useful when verifying the interaction of frequency based phase back functions with back-up systems based on active power measurements.

3. Bang-bang tests for verification of thruster ride through and recovery

Fault ride-through capability is an essential attribute in DP power plant operating with closed busties. For some DP class notations, it is proven by live short circuit and ground fault testing. This type of test is carried out at the DP FMEA proving trials but there is a need to confirm the ride-though capability periodically to have a high degree of confidence that the thrusters will ride through voltage dips. Thruster systems which are designed with a high degree of independence from other thrusters can be tested individually as autonomous units. Thrusters designed to these principles derive all power for the thruster drive and its auxiliary systems from the main HV feeder.

Confidence in the ability of the thruster to ride through voltage dips can be enhanced by cycling the main power breaker rapidly through an open and reclose sequence. Although this does not completely reproduce the conditions experienced by the drive during a main power distribution fault it does provoke the drive to engage its ride-though function. A longer interruption of main power can be used to provoke the blackout recovery sequence to operate. In this way, the logic that controls these functions can be verified conveniently and periodically. Data logging functions within the drive and its infrastructure record the action of the control logic allowing it to be scrutinised for evidence of deterioration or malfunction. A system that has been designed with autonomy as one of the key attributes lends itself to ease the burden of testing as described above. Such testing can be easily done when non-critical operations are being undertaken rather than take the vessel out of service and incur non-productive time. When autonomy has not been achieved by design, such testing will require the vessel to suspend her industrial mission. A suitable operational window will be required. All these factors contribute to precluding the potential that this testing will be carried out unless it is planned to be part of a scheduled survey.

4. High reliability services for blackout recovery

Blackout recovery is an essential risk reduction measure even for the most robust power systems. The reliability of the blackout recovery sequence is enhanced by ensuring that generator engines have all the auxiliary services they require as soon as possible after recovery begins and that there are multiple ways of powering and providing these services. One of the most critical activities is restoration of fuel pressure. When fuel pressure is low, the engines may start, but fail to develop sufficient power hampering blackout recovery. Auxiliary pneumatic fuel pumps are a well-established means of ensuring fuel is being delivered to the engines before electrical power is available. These pumps derive their power from the rig’s compressed air supply. It is expected that blackouts are rare events on well designed power plant and so the pneumatic pumps may not be required very often. To improve confidence that the electric and pneumatic pumps will operate successfully on demand, the control unit for the motor control centre is arranged to start them periodically and confirm their correct operation before shutting them down again as shown in Figure 6. Additionally, multiple power sources are provided for the electric driven pumps to ensure that there is the highest possible probability of providing power to them.

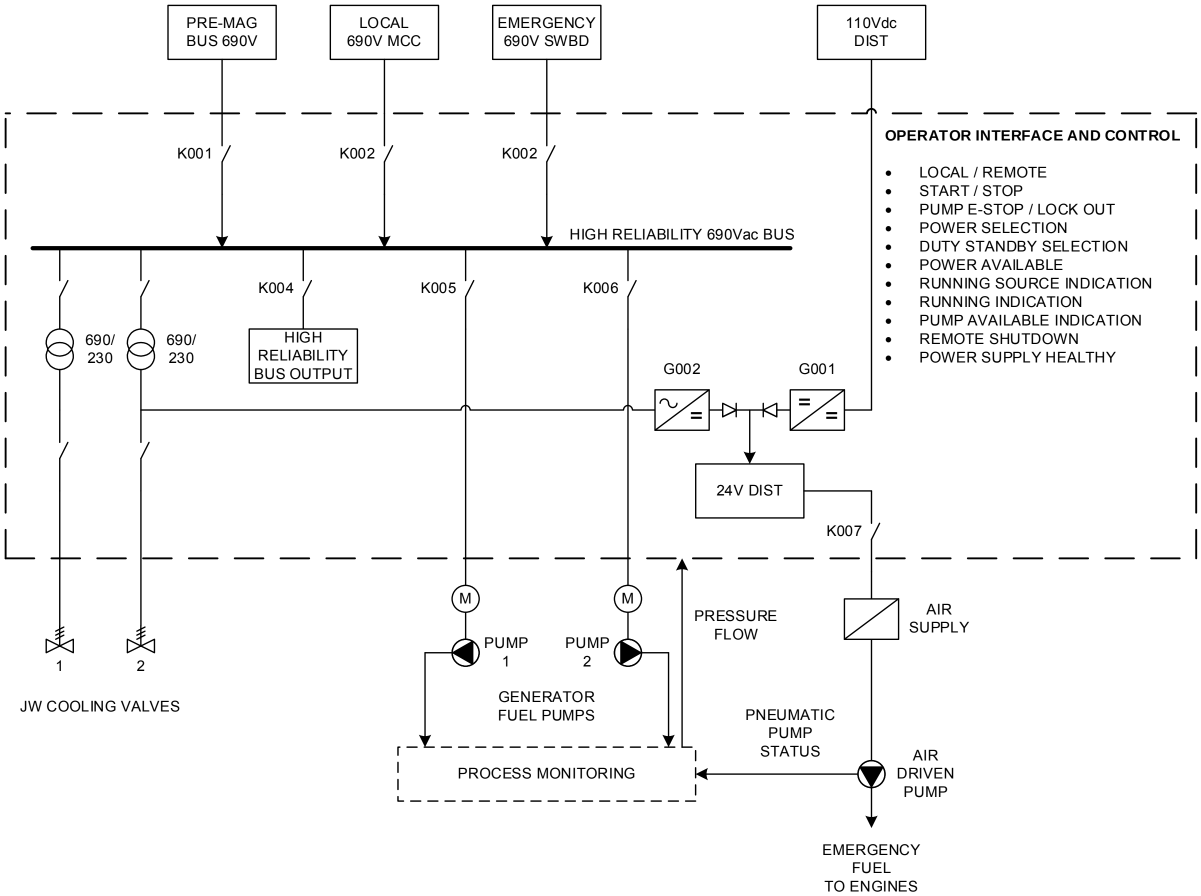

Figure 6 High Reliability Motor Control Centre

5. Control of user configurable settings

A by-product of providing the infrastructure for high speed data logging over networks is that it becomes relatively convenient to provide connections to digital controllers such as governors, AVRs, synchronizers, drive controllers and protection relays. Ensuring these digital controllers are programmed with the correct software revisions and the correct parameters is part of the independent verification and validation process. User configurable settings can be vulnerable to well-intentioned adjustments aimed at resolving some apparent malfunctions. Unfortunately, such adjustments may have unintended consequences and have been causal and contributory factors in DP incidents. Parameters may be changed when units with site specific parameters are swapped or replaced with units from stores. There are also documented cases of control parameters changing themselves due to hardware faults. Failure to store parameters in non-volatile memory can cause controllers to restore their default settings on power-up rather than the parameters that were developed as part of system tuning. The potential to adversely affect the performance of many control systems exists if controller power is cycled as part of ESD testing for example. Traditional measures to control software revisions and parameters often rely on methods that limit access in some way. Unfortunately, these methods are not as secure as they could be and do not protect against spurious or inadvertent parameter changes. Checking parameters by conventional means is a time-consuming activity requiring operator intervention.

When all the digital controllers in a DP system can be interrogated through the networks provided for data logging, it becomes possible to develop systems which periodically confirm their software revisions and essential parameters and alert the crew to unexpected changes. Parts of the process of developing such system is to ensure that the local devices used for interrogation can only read the parameters and do not themselves introduce potential common cause failures. Robustness in this aspect of the design can be ensured by following the overall split in the redundancy concept and ensuring that any common point created by servers is well isolated and electrically, and logically remote from the controllers themselves to ensure it poses no threat to their operation. It is however essential to confirm with the controller manufactures that the action of reading the controller's memory has no effect on its operation. Figure 7 shows the RS485 connections to individual controllers within a single generator switchboard section. Similar arrangements are provided for each thruster. The controllers are interfaced to Green Bee media convertors. Green Bees are versatile, configurable units with onboard processing and storage capability. The Green Bee performs the comparison with the approved parameter and software revision list and alerts the crew to any discrepancy.

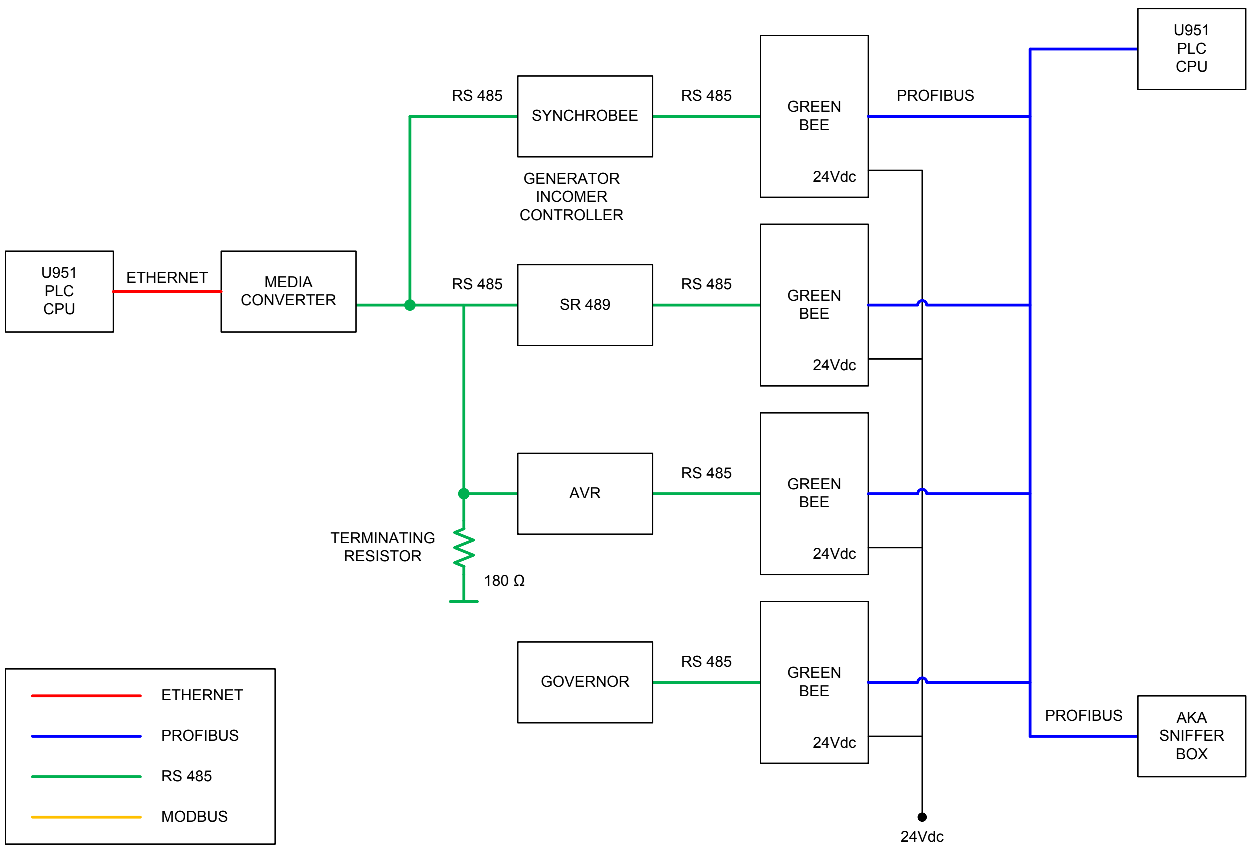

Figure 7 Profibus Gathers Essential Data on Controllers

6. UPS battery condition tests

AC and DC Uninterruptable Power Supplies (UPS) are ubiquitous in DP systems and provide three important functions. They provide a clean source of power free of distortion, spikes and voltage dips associated with the normal operation of a power system. In the case of power plant operating with busties closed they are essential to prevent voltage dips in the power distribution system causing control systems to malfunction simultaneously in more than one DP redundancy group. They are also useful in all power plant configurations to ensure that essential controllers remain operational to perform the blackout recovery function to prevent lengthy reboot times extending blackout recovery.

Such is the number of UPSs in modern DP vessel designs that confirming their battery endurance by traditional means is time consuming and disruptive. In vessels built to IPV principles, all UPSs have an automatic self test function that periodically confirms and logs battery performance during a controlled discharge test. Deterioration in defined performance characteristics may indicate the onset of battery failure. Staggering the automatic test sequence between UPSs prevent multiple, and previously undetected battery failures, causing failure effects exceeding the severity of the worst-case failure design intent.

7. PRS & DPCS

Drive offs are relatively rare events but can be one of the most challenging failure conditions to recover from when they occur. Where the drive off is caused by the DP control system following erroneous position reference system data it can be challenging to identify which PRS is accurate. In other cases, the mathematical model rejects all the position references.

The discussion of IPV principles has so far focused on its application to power systems and their associated control systems. Work is ongoing by several different stakeholders to examine the application of IPV to the DP Control System (DPCS) itself and its associated Position References Systems (PRS) and sensors. Improvements in the quality of affordable Inertial Navigation System (INS) technology has made it possible to conceive of a real time independent verification system for the DP Control System and its references and sensors. Such a system would monitor the position information being used by the DP system and provide independent confirmation that vessel movements detected by the various PRSs is genuine and not caused by measurement system errors or other malfunctions. This system could potentially form part of a decision support tool for the DPOs which drives a dashboard providing information on the quality and integrity of PRS in an intuitive form. Such developments have already been discussed in MTS TECHOP_ODP_14_(D) (PRS AND DPCS HANDLING OF PRS).

8. Confidence Number

There is nothing novel about the concepts of condition based maintenance and condition monitoring which is already widely used in planned maintenance and as part of verification schemes. Its application to the verification of DP system integrity is relatively new.

The DP community has signaled its readiness to move away from calendar based DP system verification at various industry forums and adopt condition and event driven verification schemes which add real value to the process. The true nature of the verification scope becomes apparent when it is enabled by technology and not constrained by out-of-service time or limited by crude test methods.

Verification can be subdivided into two parts:

- Periodically confirming the performance attributes of active functions - It may be necessary to arrange for conditions that test the limits of defined performance criteria.
- Testing the operation of dormant functions – Typically protective functions or standby redundancy – It may be necessary to arrange real or simulated test conditions which trigger the protective function response.

An ecosystem of sensors, highspeed data loggers and test functions enable the use of techniques for data aggregation, pattern recognition, machine learning and AI. The provision of a wide range of sensors including, voltage, current, temperature, humidity, pressure, magnetic flux, vibration and light levels allows a very broad assessment of equipment condition. The data so obtained can be used as input to the verification schedule. A confidence factor for each subsystem and redundant equipment group is derived from this data and used to initiate activities designed to restore that confidence factor. Confidence in system integrity is eroded by:

- Time
- Lack of activity
- Evidence of anomalous or erratic behaviour.

Figure 8 shows the general principle of using confidence boosting activities to 'reset' the confidence level in a particular piece of equipment and extend the time before more intrusive verification is required. The verification schedule may be variable and the point at which items are verified ranges from 'continuously' for the most critical elements to 'once-in-a-lifetime' for those elements which are considered to be so reliable that their failure is not foreseen within the lifetime of the vessel.

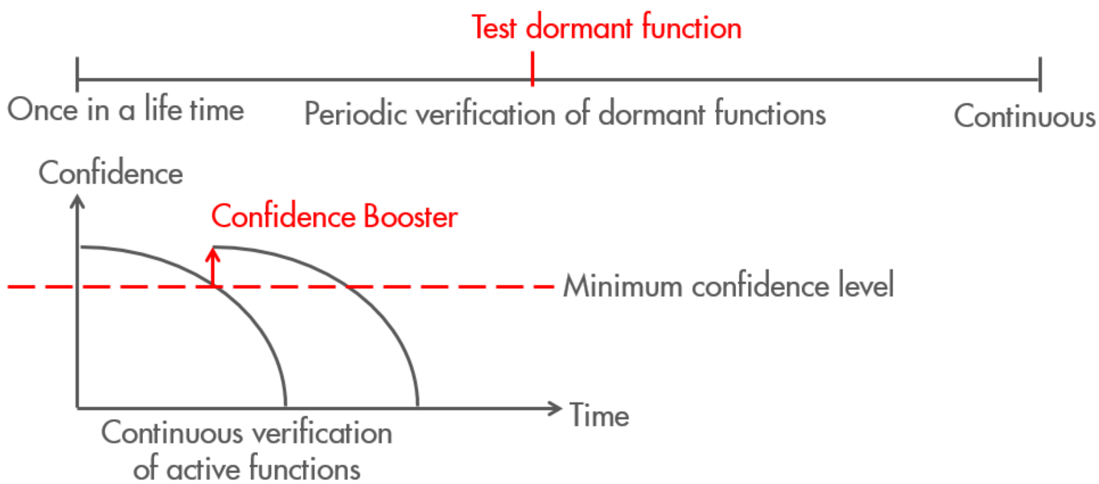

Figure 8 Concept of Confidence Number or Factor

9. Survey

The discussion in this paper has focused primarily on verification methods based on testing and monitoring. Traditional verification schemes also have a strong survey element which cannot be entirely replaced by monitoring and testing. An item of equipment could potentially pass all tests applied to it but be a single thread away from falling off the bulkhead. Environmental sensors can play some part in filling this gap, as can remote survey functions such as cameras carried by the crew and drones. The extent to which such methods are adopted may be determined by the classification societies. Vessels which undertake frequent port calls may be able to rely on more traditional survey methods.

Conclusions

DP systems and other mission critical equipment designed for IPV are monitored and tested by automatic and semi-automatic systems for evidence of deterioration and malfunction. Dormant functions such as protection systems and standby redundancy is periodically exercised in a manner that boosts confidence that they will operate successfully on demand. These techniques are applied in a manner that reduces exposure to non-productive time and reduces the cognitive burden on those performing the tests. High speed data logging is the backbone of IPV techniques which can be implemented on all essential systems to ensure robustness and resilience. The concept of a 'Confidence Number' can be used as a means of triggering activities which restore confidence in system integrity.

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[1]. Wu, Y., Bourgeau, E., Muddusetti, S., Sun Z., 'To "Bees" or Not to "Bees"' – Bees the Basis of Confidence, Dynamic Positioning Conference; Houston, October 2016.