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Design Review - Fit for Purpose

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"Design Review - Fit for Purpose"

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1.0 Introduction

Offshore exploration and production calls for extensive use of offshore vessels of all types and sizes. These vessels are essentially floating platforms supporting activities associated with the exploration, development and maintenance of oil and gas fields. The safety aspects of operations such as drilling, well stimulation and those involving the deployment of subsea divers are extremely sensitive to station keeping capability of the vessels employed. The consequences of uncontrolled excursions are potentially catastrophic in terms of loss of life and damage to equipment and environmental damage. Project losses in terms of delays and capital expenditure have also to be taken into consideration.

In the early days, particularly in the North Sea, when there was little regulation concerning offshore vessels, a number of serious incidents occurred involving DP vessels. This lead to the necessity for the charterer to impose on the vessels owners DP audits and trials to determine fitness for purpose before a DP vessel was taken on hire. Modifications and limitations were recommended by the auditors where deficiencies were found and this had the effect of reducing the number of incidents. Today regulation and the continued need for audits or design reviews have continued the downward trend in the number of incidents with the incidents that do occur being of much less seriousness. However, from time to time, new technology and equipment introduced perhaps before being fully proven can provoke a major incident. Consequently, in spite of the regulations in force today, there is still a need for technical audits or design reviews to ensure a vessel has a capable and safe DP system and is fit for purpose. Wavespec Limited personnel have carried out DP audits and trials worldwide but most of this work has been gained in the North Sea environs. Wavespec Limited's believe is that should one deficiency be uncovered during an audit which could potentially result in a serious incident, then the audit is fully justified.

So what does constitute a capable and safe DP system? Quite simply it is one in which any single failure cannot result in a loss of station keeping ability. For example, all thrusters taking their power supplies from a single switchboard is unacceptable on the basis that a short circuit on the bus bars of that switchboard would have disastrous consequences. It could be argued that the risk of such an occurrence is extremely small, but it is one which could nevertheless happen and cause a blackout resulting in a catastrophic event. Prudent operators take the view that no matter how slight the probability of a failure, it will happen and happen at the worst possible moment. This leads to the concept of redundancy. In the example above, the switchboard would be split into two sections coupled by a bus tie breaker with half of the thrusters powered from one section and half from the other section. The thrusters would be arranged such that, on loss of one section of switchboard, only half of the alongships and only half of the athwartships thrust would be lost. In order not to lose position, the vessel would be limited to 50% capability on thrust in each direction.

2.0 Consequence Classes and Equipment Classes

The concept of redundancy leads further to the question of how much redundancy is required in the DP system. The location in which a DP vessel is allowed to work and the scope of the work it is going to carry out should be governed by the amount of redundancy the vessel has in its DP system. This has been addressed by the NMD and IMO and has led to the introduction of "Consequence Classes" and "Equipment Classes".

The Norwegian Maritime Directorate (NMD) grouped the consequence of failure into four classes: Consequence Class 0, which are operations where loss of position keeping capability is not considered to endanger human life or cause damage; Consequence Class 1 operations which are operations where damage or pollution of small consequence may occur in case of failure of the positioning capability; Consequence Class 2 operations which are operations where failure of the positioning capability may cause pollution or damage with large economic consequence, or personnel injury; and Consequence Class 3 operations, which are operations where loss of position keeping capability will probably cause loss of life, severe pollution and damage with major economic consequences.

IMO defines the vessel equipment classes by their worst case failure modes. For Equipment Class 1, loss of position may occur in the event of a single fault. For Equipment Class 2, a loss of position is not to occur in the event of a single fault in any active component or system. Normally, static components such as manual valves and piping systems are not considered to fail provided they can be shown to be adequately protected from damage and reliability is proven. Single failure criteria include any active component or system, e.g. generators, thrusters, switchboards, remote controlled valves, etc., together with any normally static component (cables, pipelines, manual valves, etc.) that cannot be shown to have adequate protection from damage or have proven reliability.

For Equipment Class 3, the single failure modes include those in Equipment Class 2 plus that in which any normally static component is assumed to fail. Additionally, all components in any one watertight compartment are assumed to fail due to the effects of fire or flooding and all components in any one fire subdivision are assumed to fail due to the effects of fire or possibly flooding. ***A summary of the vessel requirements to suit these Classes is given at the end of this paper.***

The design of a vessel's DP system complying with Equipment Class 3 would therefore have a power system divided into two or more systems so that failure of one will have no effect on the other(s). The power generation system will have a minimum of two enginerooms separated by an

A60 bulkhead. In the case of a two engineroom system, half of the generating capacity would be located in one engineroom and the other half in the other engineroom. The switchboard room would similarly be split into two rooms with half of the switchboard located in one room and half in the other room. The sections of bus bars would be coupled by two bus tiebreakers one located in each section of switchboard. The supplies to the thrusters would be configured such that only half of the thrust capability in both alongships and athwartships direction is lost should a section of switchboard fails. Thrusters would be located in compartments such that those located in a single compartment would not be supplied from both sections of switchboard. With the effect of fire being considered, a backup DP control station would be located in a separate compartment to that in which the main control station is located. Cabling to items of redundant equipment would not be run through the same compartment but be run segregated such that a cable blow out or a fire would not affect both units.

It follows from these Consequence Classes and Equipment Classes that a Consequence Class 0 operation can be carried out by the equivalent of an Equipment Class 1 vessel with little or no redundancy or, indeed, a vessel with more redundancy, but a Consequence Class 3 operation can only be carried out by the equivalent of an Equipment Class 3 vessel with considerable redundancy.

Prior to the audit taking place, it is established from the Charterer of the vessel what “Consequence Class” operation will be carried out and hence the "Equipment Class" which will be required in the vessel. If the vessel is to be operated on full DP and an unintentional loss of position can be tolerated, then DP to Class 1 should be chosen. On the other hand, some clients will require Class 2, but require a Class 3 operation for critical operations. The trade off between cost and benefit should be considered when an "Equipment Class 3" vessel is requested.

3.0 Auditing of DP Vessels:

Wavespec carries out formal FMEAs (Failure Modes and Effects Analyses) for new buildings, conversions and existing vessels to identify the capability and safety of a vessel’s DP system. However, auditing and sea trials of DP vessels prior to charter, by oil majors in particular, together with annual trials on behalf of vessels’ owners comprise most of our offshore work.

3.1 DP Checklist

The auditing of vessels to be chartered, ie. determining a vessel’s “fitness for purpose”, is carried out using a DP Audit and Trial Checklist which was originally developed by Shell International Marine and is now an industry standard. The audit is usually carried out with the vessel alongside and the DP trials carried out at sea in a location representative of the work site, eg. similar water depth, current, etc. The checklist has evolved and grown over the course of time as the causes of incidents of loss of position are made known and are understood. The IMCA (DPVOA) reporting system which allows operators to anonymously report DP incidents or “near misses” has certainly helped to “spread the word” and reduce the number of DP incidents.

The basis for this checklist was the 1983 Department of Energy/Norwegian Petroleum Directorate "Guidelines for the specification and operation of dynamically positioned diving support vessels". These guidelines defined a DP System as "all equipment and components involved in retaining the vessel in its required postion", and stated the principle that "no single fault should cause a catastrophic failure which would, of itself, cause risk to divers". However, these 1983 Guidelines have more recently become outdated in some aspects, particularly in what constitutes a worst case failure mode. The UK HSE questioned the guidelines and now recognise the loss of a switchboard or engineroom to be a worst case failure.

Whilst this DP Audit and Trial Checklist has always considered the worst case failure as being loss of a switchboard and hence loss of a group of thrusters or loss of an engineroom, it has been updated to recognise and give due consideration to the guidelines issued by the Norwegian Maritime Directorate, IMO, IMCA (DPVOA), the classification societies (notably DnV and Lloyd’s Register), the United Kingdom Offshore Operators Association (UKOOA) and the UK HSE.

The Checklist is not confined to diving support vessels and can also be used to assess the DP systems on other types of vessel which may be required to undertake DP operations, such as ROV survey, pipe reel, cable laying, crane or drilling vessels.

3.2 DP Audit

The audit section of the DP Audit and Trials Checklist is essentially a generalised one since no two vessels' DP systems, even if the vessels are of the same type, are installed in exactly the same way with regard to, for example, the electrical distribution systems, as modifications are often made over the course of the vessel’s life.

The audit includes a review of the requirements of the individual Operator, including the specific workscope details and the environmental conditions prevailing at the worksite so that the vessel’s capability can be matched to the task to be carried out. It is the job of the auditor to assess the risks due to possible deficiencies in the original design and recommend modifications or changes to procedures to reduce these risks. Frequently, the auditor will be called upon to be involved in the client’s project meetings to advise on any pit falls in using a particular vessel for a specific workscope that may be apparent prior to the vessel being audited.

During the audit, a review is also made of those documents and certificates that are required to be held on board by statute to ensure compliance with legislation. Documentation forming part of the DP system such as the DP Log Books, DP Operations Manual, including the DP Operators’ Pre-DP setting up procedure checklist, and the Emergency Operations Procedures Manual are also reviewed as part of the audit.

Prior to the audit taking place, the DP Audit Checklist questionnaire may be forwarded to the vessel's owners for completion by a non-specialist with the assistance of staff onboard the vessel. Analysis of the data gathered to assess the vessel's DP capability must then be undertaken by personnel experienced in DP systems when they visit the vessel.

3.3 DP Trials

Before a DP vessel is employed on charter, after it has undergone a refit, or when it has been modified, it should undergo a series of DP proving trials. These should include sea trials in which the vessel's stationkeeping and auxiliary support systems should be thoroughly tested under normal and abnormal conditions. To achieve this, the DP Trials Checklist is made up of three sections. The first section covers the function tests of the different components comprising the DP system and the ability of the system to maintain accurate positioning. The second section covers the failure modes tests which demonstrate the system’s ability to withstand a single failure. For example, the failure modes tests include tests to fail the thruster feedback signal to confirm that the thruster pitch does not drive to maximum pitch under this circumstance, ie. it fails safe, with an alarm generated. The third section covers any options that may be fitted such as auto track, fifi mode taking into account the force generated from fire monitors, and so forth. They should, if conditions and time permit, culminate in a DP endurance test under the vessel's normal operating conditions. The systems to be demonstrated during the trials include power generation, electrical distribution, thrusters, the DP computers and position and environmental reference systems.

Where possible the trials are performed in a situation representative of the intended worksite and where accurate monitoring of the vessel's position can be achieved. The results of these trials are used to confirm or revise the vessel's performance capability statements. The trials usually follow the programme agreed with the operators of the vessel, but should not be restricted in scope to the programme; any additional tests which are seen by the auditors during the trials to be necessary to prove the integrity or safety of the vessel's positionkeeping capability should be carried out after consultation and agreement with the operators.

During the trials, DP procedures laid down in the DP operations manuals are checked against actual practice and the competence of the DP operators confirmed with regard to familiarity with DP equipment and procedures.

In the event of any modifications being made to the DP system since the previous full audit and trial, then a further full audit and trial must be carried out and the Checklist altered to reflect the changes.

4.0 Annual DP Trials:

In recent years, DP vessel owners became concerned that over testing of the DP systems of their vessels could cause damage or reduce the life of the equipment, particularly the exercising of electrical breakers. It was not unusual to hear of complaints arising from too frequent audits, with repeated requests for “blackout tests” and load switching of circuit breakers. These complaints were justified as there is no need to stress equipment in the way some auditors were reported to do. Also, with the vessels on the spot market being subjected to an increased number of audits and trials over the offshore season, there was the increased possibility of mal-operation of equipment and damage during the trials as the personnel were testing failure modes not normally encountered.

Because of these problems, an Annual DP Trials scheme was set up whereby the response to failure modes, particularly components of the main switchboard, were demonstrated to an independent auditor on an annual basis, with the resulting report being available on the vessel to any auditor representing a prospective charterer. In this way, the heavy testing which the owners viewed as being detrimental to the equipment would be carried out once per year with an auditor visiting the vessel during the intervening year confining the testing to alarm demonstrations and function tests. However, the system is only valuable if the reporting format gives a clear indication of the events of the trial and the results of the tests, together with supporting documentation. An auditor receiving the document will then have the complete picture so that an initial suitability assessment can be made even before visiting the vessel. In this way vauluable time is not lost auditing an unsuitable vessel.

Testing once per year does allow more time to be spent confirming the system is operating correctly than if the vessel were being subjected to precharter audits and trials during which the time for testing is very restricted. Also, should any problem be found during trials, it is better to be found during the Annual Trial rather than during a precharter trial when the vessel may be mobilised with a full complement and ready for work.

5.0 FMEA:

During the design stage, normally a Failure Modes and Effects Analysis (FMEA) is carried out. Indeed most classification societies require a FMEA to be carried out as part of the class notation. This is effectively a formalised “what if” scenario, ie. it looks at all components of the DP system and asks the questions “What if this component fails?”, “What are the compensating provisions if it does fail?”, “How is the failure conveyed to the operator?”, “Is the DP system still operating (albeit in a reduced capacity)?”. If the FMEA identifies a potential problem which may result in a single point failure, then the designers are informed and the design modifed to eliminate this single point failure. It is generally much more difficult to correct a fault after the vessel is built so the FMEA should run concurrently with the design phase. The FMEA is essentially a desk top study which looks at all of the “as built” system drawings. In some cases it is impossible to determine the failure modes owing to the number of subsystems which interact dynamically when the system is operational. Any “grey” areas are noted and and a sea trials programme formulated which includes tests to prove practically the effects of failure. FMEAs have been carried out after a vessel is built is operational but should any potential single point failures be identified it is far more difficult to make modifications. If modifications can not be made, the risks can be mitigated by operational changes possibly by restrictions and limitations to the vessels working envelope both in terms of location and weather depending upon the failure mode found.

If the FMEA reveals only one single point failure that could cause a position loss then the cost of carrying out the FMEA is negligible compared to the potential economic impact that the position loss may cause.

As can be seen, the FMEA is a very valuable document to the auditor. It is a very good basis with which to start analysing the subject vessel's systems. However, sadly, most FMEAs are not updated sufficiently and reflect the "as built" and not the "as fitted" condition. The FMEA should be included as part of the vessel's quality management system and updated as soon as any modifications are made to the vessel's DP system. Consequently, the FMEA alone is not sufficient and it is the task of the auditor to seek out these changes and assess the implications.

6.0 Auditing Techniques:

We are of the opinion that a team of technical experts of varying disciplines are best suited to the auditing and testing of DP vessels. They have the knowledge to understand the technical complexities of a DP system. Normally a marine engineer with control experience and an electrical engineer would comprise the team. We would expect the team leader to have a minimum of five audits/trials under the belt before leading the team. All auditors will have the relevant offshore training requirements.

On arrival on board, the team would require adequate lead time to familiarise themselves with the vessel as the system cannot be tested properly unless the systems are fully understood. This familiarisation is achieved by carrying out the audit or design review prior to the trials. The checklist can seem long-winded with completion involving much data gathering but the prudent auditor guards against allowing the checklist to "drive" the auditor and not allowing the data gathering process to take precedent over the analysing process. The checklist is used as a tool or an "aide memoir".

7.0 The Audit or Design Review

The power plant system includes all the equipment to generate power, ie. the generating engines and their supporting systems such as the fuel systems, lubricating oil systems, cooling water systems, air start systems, control systems, the electrical generators and the electrical distribution system. All these systems need to be studied to assess the impact a failure would have on the overall DP system.

Whilst it should be ascertained from the workscope what Equipment Class the vessel's DP system should comply with, the following comments refer to Equipment Class 2 (and above in some cases) and give an idea of the areas which the auditor has to cover during the course of the audit to determine fitness for purpose. Some areas that are included in the checklist may seem obscure, such as air conditioning and ventilation, but it is quite common for duplicated equipment placed in the same compartment to overheat without suitable air conditioning and cause loss of not only the duty unit but the back up unit as well.

The age of existing equipment and their maintenance levels are addressed together with the running hours of main engines, generators and thrusters to next overhaul, and lub. oil/hydraulic oil sample results.

7.1 Design Criteria and DP Capability Plots

The maximum continuous stationkeeping capabilities for full DP operations and under various failure mode conditions should be forecast. Capability plots or envelopes of the maximum tolerable environmental forces and their relative heading are usually produced by the DP system manufacturer and held on board. These are theoretical plots showing the operating envelope within which the vessel will hold station to a satisfactory confidence level under certain weather conditions, being expressed in terms of direction and magnitude of wind, associated wave drift force and current combinations. A sequence of plots are produced which show the capability under various failure conditions, eg. worst case scenario (usually loss of a group of thrusters, ie. loss of one section of main switchboard or one engineroom), loss of a thruster, etc. These plots are theoretical and are only as good as the data inputted to the programme but are considered a reasonable guide. The auditor will assess the vessel's capability against the predicted environmental conditions at the worksite. Limitations or restrictions will be placed on the vessel if the capability is deficient in any way. For example, if a vessel is working on the weather side within the 500metre safety zone of a platform, a move to the lee of the platform will be necessary if the combined wind and current effects increase to the level that a loss of position will result if a "worst case" failure scenario occurs. Some DP vessel owners will request that as far as practicable these plots be verified if and when the vessel is waiting on weather.

7.2 Computer Hardware Configuration

For a vessel being considered for tasks where failure of position keeping would potentially result in pollution, major damage or loss of life, the dynamic positioning system should have such redundancy that the failure of any one part will not affect the station keeping ability, irrespective of mode of operation. Failure of any one position sensing system, or part of the dynamic positioning system, must be indicated by audible and visual alarms at the DP control centres. The dynamic positioning system should be equipped with, as a minimum, a duplex computer control system with provision for monitoring and alarms. A duplex system typically consists of two control computers with constant automatic checking either between them or by a supervisory computer. Class III vessels will have three computers each carrying out the same analysis and utilising triple voting software. Sensors will be triplicated and continually connected to, though not necessarily selected into, each computer.

7.3 DP Software

Normally during the audit there is no formal analysis of the software. The DP computer is treated as a "black box" and during the DP trials, a function test will be carried out such that a request by the operator will be input to the computer via the operator interface and should the expected response be achieved then the software is deemed to be correct. However, should an unexpected response occur, then an investigation would be instigated in conjunction with the DP system manufacturer. This part of the analysis is very much dependent upon the experience of the auditor.

During the audit the correct version of software is verified by checking the maintenance records.

7.4 DP Computer Power Supplies

Provision should be made to ensure that power supplies to computers and controllers are safeguarded at all times. This should involve provision of a duplicated back up supply for each computer in the form of an uninterruptable power supply (UPS). The requirement is for the UPS to provide output power for a minimum of 30 minutes when the mains power has failed.

7.5 DP Alerts and Condition Monitoring

The status of the vessel should be brought to the attention of relevant DP Operations staff at all times. Audible alerts to warn personnel in the main operations areas of unintentional changes in the DP operational status of the vessel should be manually initiated by the DP operator from the DP Control Room.

Certain main functions should be monitored at frequent intervals and critical limitations should be alarmed. The latter should be included in the DP software as a "consequence analysis" which gives a warning to the operator that that the limitations of the system are being exceeded and that, if the single failure that is the subject of the warning should occur, a loss of position will result. A Class 2 or Class 3 DP computer system will include "consequence analysis" as standard.

It is imperative that on a failure an alarm is given to warn the operator that the failure has occurred so that he can take corrective action. A failure is not considered to be a failure unless it is revealed by an alarm or otherwise. A hidden failure giving rise to another failure is considered to be a single point failure.

7.6 Position Reference And Environmental Signals

At least three independent position reference systems should be available at commencement of operations. These need not all work on different principles but, if similar systems are to be considered as independent, they should not be subject to common mode failures, e.g. common power supplies should not be allowed, or if two DGPS systems are used then it is recommended that two independent systems are fitted with the differential corrections being derived one via a radio signal and one via the InMarSat and the system antennae should be as widely separated as possible.

Heading measurement is very important. In a system with two gyros, in open water with no fixed structure to reference against, a failure of a gyro may confuse an operator. In this case, three gyros with triple voting software would be expected.

7.7 Thruster Interface Controls

In the event of a pitch control malfunction due to loss of command signal, feedback signal or control power supply, or when the control error becomes unacceptable, on no account should the thrust output from the faulty unit be set to maximum, i.e. thrusters should not go to full thrust. Should a fault occur in the final hydraulic control element and the pitch is set to maximum, the control system should detect this mismatch between set point and feed back stop the motor, usually automatically. Alarms must be generated on failure.

If two azimuthing thrusters are fitted in close proximity to each other, barred zones or cut off areas between adjacent azimuthing thrusters may be required to prevent interference between thrusters. As the azimuthing thrusters rotate, one of a pair may have its pitch reduced or it may be prevented rotating in a sector in line with the other thruster. The thrust control strategy should be determined by the DP control system manufacturer and these barred zones or cut off areas should be investigated to determine how these may affect DP capability.

7.8 Control Centres And Modes Of Operation

Each DP Control centre, if more than one is fitted, should be provided with a complete set of information displays and controls and communications to allow it to operate independently. A Class III vessel should have a back up control station located in a position away from the main control station and separated from the main control station by an A60 bulkhead.

7.9 Electrical System

The vessel's electrical installation should have been designed such that failure of one component or subsystem will not result in loss of total electrical supply to essential services.

Generator Ratings and Load Balance:

As an ideal, all main generator sets should be similarly rated. The capacity of the system should be sized to ensure security of supply such that services essential for safety will be maintained in the event of failure of any one prime mover or electrical generator. A load balance of the system should be undertaken and be made available to the auditors.

Compartments containing main generating sets should be independent with respect to structure, piping, ventilation, etc.

Main Switchboards:

In order to minimise the potential damage caused by a major fault or fire, as a minimum, the switchboard should be split into two sections with each section feeding half of the vessel's essential services. Each section should be located in a separate switchboard room separated by a fire retardant bulkhead. The construction of the switchboard itself should be robust and segregation of busbars should be such that major electrical faults are minimised. If the vessel complies with Equipment Class III, there must be two bus tie breakers separating the two sections of switchboard one in each section of switchboard such that if one switchboard room suffers a fire the tiebreaker in the unaffected switchboard room will be able to operate.

It is not recommended that a switchboard be located in a control room from a safety viewpoint.
Fault Level/Discrimination:

All circuit breaker ratings should be capable of make and break of potential short circuit current levels. Switchboard busbars should have been tested to withstand the calculated fault level of the system. At the design stage correct discrimination should have been achieved by correct selection and setting of protection relays and evidence of this is sought during the audit.

Segregation and Redundancy:

Where possible, the vessel design should be such that feeds to essential services are segregated to prevent a single failure causing disruption or damage to both supplies. Adequate redundancy should be allowed in the sizing of all equipment.

Emergency Switchboard:

The emergency switchboard should be located in its own room. Where an emergency generator is installed, this must be sited in the same room as the emergency switchboard. All services fed from the emergency switchboard should have completely separate and independent cables. The design should allow for the emergency generator to supply the main switchboard, for re-activation of the main plant, should the need arise.

7.10 Power Distribution Systems

The power distribution system, by design, should be arranged to allow automatic start up of a standby system in the event of a failure occurring in the duty system.

High Voltage (3.3KV and above):

High voltage power distribution switchboards should be of a reputable manufacture, and should consist of dust and moisture proof deck mounted enclosures housing the required services. Circuit breakers, vacuum contactors and fuse combinations should be used for the control of the circuits connected to the system. Appropriate earthing apparatus must be provided for all high voltage equipment.

Low Voltage (440/660V):

Construction of low voltage distribution panels should be generally as those for high voltage equipment. Starters should be preferably of the drawout pattern. Alternative supplies should be provided for critical services, and loading levels of the various circuits should be such that overloading does not occur under normal operating conditions.

Low Voltage & Battery Systems:

The low voltage systems, usually control voltages, should be designed to prevent a single failure causing loss of redundancy and battery systems, where fitted, should be designed such that failure of a charger rectifier unit does not affect the system operation. The battery system utilised should have been designed to minimise maintenance. The security system should be arranged with full back up facilities and alarms.

Typically, it is the low voltage systems which give rise to potential single point failures as during the life of the vessel modifications are invariably made. These modifications are sometimes made without due regard to the original redundancy concept and cross feeds and commonality as a result of modifications have in the past been found to be the cause of position failure.

Uninterruptible Power Supplies (UPS):

UPS units should be provided where the loss of a supply could seriously affect the vessel's DP capability. This will apply to a computerised power management system with dual processors where fitted. Guidelines require that a UPS should be capable of supporting the load demand for a minimum of 30 minutes duration.

Cables:

All cables should be carefully chosen to minimise the adverse effects of heat and moisture. Cables from emergency switchboards, which are not connected to equipment located in the machinery spaces, should not pass through those spaces. Separate cables should be provided for essential control circuits. Where cables pass through decks and bulkheads the penetration must be in accordance with the classification of the deck or bulkhead concerned.

Redundant dual data networks should be kept segregated by running in widely separated cable routes to prevent a fault on one net affecting the other net. Should it be found that redundant cables pass through a single compartment, if the cables cannot be rerouted, then this compartment, in particular, should be protected from the effects of fire.

7.11 Power Management System

Where the vessel design incorporates a power management system, flow diagrams which show the functioning of the system will be studied during the audit so that meaningful tests can be carried out during the sea trials.

Preference trip systems, if installed, should be checked and proved operational. Generators should be arranged for auto cut-in on loss of voltage or frequency of main switchboard. If the vessel is fitted with a power management system or generator automatic load control system, it should be a redundant system and the start/stop commands to the main generating sets should be arranged for auto start, manual stop.

Usually an automatic power management system is arranged to provide optimum power requirements at varying demands. Whilst automatic start/stop sounds a good idea, it is possible that some microprocessor based power management systems can fail giving out indeterminate signals and if all stop bits are sent to the generators a blackout could ensue. For this reason a dual self checking processor system is recommended and, to make doubly sure, it is recommended that the system is set for auto start / advisory manual stop of the generators.

If the main electrical system is to be operated in split mode, ie. Class 3 mode, it should be confirmed that the power management system can be operated in this mode without any limitations.

7.12 Machinery And Piping Systems

The vessel's machinery installation should be designed such that failure of one component will not result in the loss of any plant that is required for essential services, station keeping or safe withdrawal from the worksite. This will require attention to be paid to adequate back up facilities for all auxiliary machinery associated with the main power plant.

Drawings are sighted to ensure that fuel systems, sea water and fresh water cooling systems, lubricating oil systems and starting air and control air systems are redundant where necessary.

If the vessel is considered to be of the Equipment Class II type, the compartments containing DP related equipment will be examined to ensure that the installation of manual valves, piping systems, etc., ie. the “static components” mentioned above, are protected from fire and flooding. If this is not the case, the auditor may recommend that a particular compartment be manned continuously during critical DP operations.

Fuel Oil System:

Fuel systems for separate enginerooms should be independent, with separate fuel service tanks. Fuel oil booster pumps should be duplicated with the motors supplied from separate sides of the main switchboard. In most cases engines will have double skin fuel pipes and alarms on leakage collection tanks should be ensured operational. If the engines are run on heavy fuel oil, it should be ensured that electric or steam heaters and trace heating of piping will maintain the fuel temperature if a failure occurs or there is an automatic changeover to diesel fuel.

Fuel oil tank quick closing valves are examined to see if they are vulnerable to inadvertent operation. It has been known for a cleaning hose to trip the lever of a fuel tank service supply valve.

Lubricating Oil System:

Normally the lubricating system of each engine is separate with engine driven pumps. A failure would therefore affect one engine only. Sometimes the lubricating oil in the sumps are purified by a separator unit. The system design in this case has to be carefully considered as it has been known for the lub. oil to be drawn from one running engine sump and purified into another causing shut down of the engines. If there is the chance that this may happen, then it is recommended that the lub. oil is not purified when the vessel is operating on DP.

Engine Cooling Water Systems:

Normally, each engine has its own freshwater cooling system and a failure would therefore affect one engine only. Crossovers are sometimes provided between enginerooms so that coolers for different enginerooms can be used by either system and it should be ensured that this crossover system does not become a potential common mode failure.

Salt water cooling systems are usually separate, each with its own sea suction and overboard discharge. As for the freshwater systems, crossovers should not become a potential common mode failure. Similarly, a common overboard discharge for two systems could become a common mode failure.

Automatic temperature control valves are checked to ensure that, on failure of the motive power or signal, the valve fails safe and an alarm is raised.

Compressed Air Systems:

Starting air systems are normally provided in each engineroom, with a crossover between enginerooms. A failure in one engineroom should affect one engineroom only. With regard to control air, it should be ensured that loss of control air will cause a fail safe situation, eg. control valves to fail safe, either fail fix with alarm or to full cooling with alarm, otherwise alternative supplies must be arranged. Filter/driers should be duplicated.

7.13 Thrusters

Thrust unit installations should be designed to minimise both the potential interference of wash with other thrust units, sensor systems and the effect of hull surfaces on thrust unit efficiency.

Power Limitations:

Thrust units and, where appropriate, rudders should be sited to achieve fore and aft, athwartships and rotational thrust and so configured that the loss of any one thrust unit always leaves sufficient thrust in each direction to ensure that the vessel holds position and heading, when operating within its forecast operational capacity.

Thruster Or Main Propulsion Hydraulic Systems:

Normally, two hydraulic pump units are provided for each pitch and/or azimuth control system for each thruster and the system filters are of the duplex type. Maintenance of the hydraulic system is extremely important as final shuttle valve has been known to stick open due to dirt of swarf entrappment and the thruster to adopt maximum pitch. Any overhaul of these valves should be carried out in a clean “laboratory” environment.

7.14 Communications

Communication systems should be provided to ensure that immediate and clear transfer of information between all responsible parties is achieved. Essential systems should be provided with 100 percent redundancy.

7.15 Fire And Gas Detection And Smothering System

Automatic fire detection should be installed in all compartments associated with DP machinery, where these are not continuously manned.

Manually initiated smothering systems (CO_2 or alternative equally effective eco-friendly type) should be available for all machinery compartments. Some requirements such as DnV F-AMC require locally activated systems.

Attention should be paid to the operation of engineroom ventilation dampers in the event of a gas alert and the effect on the DP this may have.

8.0 Common Failures:

Of incidents which can be attributed to design or component failures, the majority of them in our experience fall into three main groups: Electrical failures; fuel oil failures; and cooling water failures. Some have already been outlined above.

Electrical failures are most prevalent and potential electrical failures are the most difficult to spot from design drawings due to the complexity of some systems and the fact that the consequences of small electrical failures such as loose connections are almost impossible to determine without lengthy and costly investigations. A problem encountered frequently on existing vessels is lack of documentation of modifications or retrofits in which the original concept of redundancy is not fully understood and therefore becomes compromised.

Fuel oil system problems are potentially the most dangerous as any fracture in the piping system can lead to fire. Any fuel problems such as a broken pipe, a valve malfunction, or water in the fuel could cause loss of all engines. Water-in-fuel detectors are recommended to be fitted in all fuel oil service tanks as a minimum. Fuel systems serving separate enginerooms should be split for redundancy, each with separate settling and service tanks.

Cooling water systems should be split for redundancy. Separate cooling systems should be arranged for each engineroom with crossover connnections. Care must be taken to ensure that if freshwater generators are installed, the redundancy of the high temperature systems are not compromised. For a Class II vessel with inbuilt redundancy and certainly for a Class III type DP system, the crossover connection should have double shut off valves as, with a single valve, the failure may mean the necessity for shut down of both systems.

Some of the problems outlined below were not revealed and lead to incidents, others luckily were revealed during audits but the potential was there for serious incidents to occur. They are intended to give a flavour for the need for a design review when a vessel is taken on charter and illustrate the depth of auditing analysis necessary to reveal these problems.

Electrical problem: After an audit was carried out, the power for a ROV spread and deck equipment was taken from main switchboard without the auditor being informed. A fault on the deck equipment was not isolated and fed back to the main switchboard causing a blackout. It should be ensured that the deck equipment is powered from a source independent to the ship's main supply so that it is independent to the DP system.

Electrical problem: We were involved with investigating an incident involving a Class II DSV in which all online generator circuit breakers tripped causing a total blackout with the vessel in a blow on position 40 metres from a platform, divers deployed and the offshore crane coupled to an underwater welding habitat. All diesels continued to run and the investigation went on to show that the automation system reclosed two circuit breakers and restored main power but the momentary blackout had stopped the thrusters which were fixed pitch propellers driven by SCR controlled main motors. Two problems were revealed. The first problem was that the blackout was caused by the over-excitation of one generator with the protection system failing to clear the fault. This generator took all the load whilst the others shed load to maintain frequency. When the overloaded generator eventually tripped, the low system voltage caused tripping of the other generator breakers. The second problem was that the resulting low voltage also caused the thruster drive protection systems to switch off the thruster drives. The SCRs had to be reset locally and this took time. Whilst no-one was hurt and only very minor damage occurred to both vessel and platform, this was a serious incident with the potential for far greater damage, loss of life and pollution. It also had the effect of a major review of auditing techniques and changes to the checklist. The risk of this happening would have been much reduced should the vessel have been subjected to a FMEA and, whilst the checklist follows a set pattern, the auditor as part of the audit now carries out an assessment of how operation of the plant impinges on the DP capability.

Electrical problem: The UPS batteries on a DSV had been replaced, all but one which was considered to be OK. During DP trials, the UPS charger was failed and as the transfer was made to battery power, the power out put failed. Noone had thought to test the system after changing the batteries.

Fuel problem: A fire was reported in a vessel with two enginerooms. A low pressure fuel oil pipe fractured and sprayed fuel droplets over a hot manifold. The fire was only noticed when smoke started to come from the engineroom ducts. It was found that the fire detection system had not activated as the detectors had been sited near the ventilation blowers and had fresh air flowing over them. No one was hurt but the engineroom destroyed. The vessel stayed on station by virtue of the generators running in the other engineroom continuing to supply power and the thrusters being within the criterion of one engineroom/switchboard failed. For some critical operations it is requested that all generators are on line.

Cooling problems: Temperature/pressure control valves adopting a non fail safe mode eg. temperature control valves shutting on loss of power air restricting cooling water to coolers.

Control air problem: On a twin screw vessel with the main engine coupled to each shaft via a clutch it was found that the control air to both clutches was common and loss of air pressure caused the engines to declutch. Separate supplies were arranged so that loss of both clutches could not happen simultaneously.

Thruster problem: Whilst the DP trials address failure modes by failing section of plant and removing wires and fuses, there is no attempt to carry out any destructive testing such as unsoldering wires. Though an incident occurred concerning an azimuthing thruster which had a feedback sensor in the form of a bridge circuit. Whilst the signal output wire was removed and the feedback circuit checked and confirmed to be fail safe during the audit, an internal wire became unsoldered and made the bridge unstable. This caused the thruster to adopt maximum pitch and the vessel to collide with a platform. It would be expected that this type of sensor is included in the FMEA and discarded for a different fail safe type.

Thruster problems: In auditing and subjecting vessels to precharter DP trials, we have found that the original commissioning trials were not exhaustive enough. A new vessel should be subjected to exhaustive sea trials but unfortunately these are sometimes curtailed due delays in commissioning reducing the sea trial time available to meet a charter deadline of due to the economic pressures for a vessel to be put to work to recoup the considerable outlay in cost as quickly as possible. We found during precharter DP trials on one vessel crossovers in the wiring of alarms and thruster control circuits anongst other potential problems. Another vessel had been working for several years with a serious failure mode in which loss of thruster pitch feedback caused pitch to travel to maximum. In this case, the standard electronic control units had not been customised to allow the thrusters to fail safe and transfer to non-follow up control.

Computer problem: Designers must be aware of what the operator may want to do during the execution of specific workscopes. On one occasion, following extensive sea trials of a newly commissioned vessel ready to undertake cable laying, the trencher was made ready on the sea bed with the centre of rotation of the vessel being chosen as the nearest point to where the cable disappeared into the water. As soon as the DPO entered a follow sub mode to follow the trencher the centre of rotation jumped back to the centre of gravity giving a 15 metre drive off.

Computer problem: We have found that on one vessel that had been operating for many years, the power supplies to the computers were common, the thinking being that “belt and braces” would provide redundancy. But a fault on the resulting cable loop between both computers would have caused a power failure to both computers and loss of all automatic positioning control.

Control problem: Problems are not necessarily confined to vessels incorporating redundancy. We tested a simplex vessel with a single DP computer and computerised joystick with functions including automatic heading control. It was noticed that a fuse was critical to the changeover between automatic DP and joystick. Loss of this fuse was not alarmed and, with the vessel on automatic DP, it was proved that with loss of this fuse remaining hidden should the automatic DP be lost then transfer of control to the joystick was impossible.

9.0 Conclusion

The development of DP systems has proved invaluable to the offshore industry, particularly in the move to more hostile environments. Problems have been overcome but sometimes the learning process can be a tough one to bear. The introduction of more indepth analyses of vessel systems such as FMEAs and annual audits has assisted in the design review and assessment of a vessel’s fitness for purpose and without doubt reduced the risk of potential incidents. Only thorough auditing will maintain a downward trend in the number of DP incidents whether serious or not. Anything that has this effect must be good and everyone involved or who will be involved with dynamic positioning offshore should be made aware of what has been learnt so far from others so that they do not have to make the same mistakes themselves.

Subsystems or Components	**Consequence Class/System Configuration**			
	0	1	2	3
Power System Generators	Non-redundant	Non-redundant	Redundant	Redundant - separate rooms
Main Switchboard	1	1	1 with bus-tie	2 bus-tie (normally open) Separate rooms
Bus Tiebreaker	0	0	1	2
Distribution System	Non-redundant	Non-redundant	Redundant	Redundant, through separate rooms
Power Management with thruster preference	No	No	Yes	Yes
Thruster System Arrangements, number of thrusters	Non-redundant	Non-redundant	Redundant	Redundant - separate rooms
Control System Auto control: No. of control computers	1	1	2	3, with 1 in backup control station
Man. control: Joystick with auto heading	No	Yes	No	No
Single man. control each thruster	Yes	Yes	Yes	Yes
Position ref. systems	1	2	3	3, with 1 in backup control station
Ext. sensors Wind	1	2	2	2, with 1 in backup control station
Vertical Ref. Syst.	1	2	2	2, ditto
Gyro	1	2	2	3, ditto
Other necessary sensors	1	2	2	2, ditto
UPS (Uninterruptible Power Supply/Battery System)	0	1	1	2, with 1 in backup control station
Backup control system in separate control station	No	No	No	Yes
Printer for register and explaining alarms	No	Yes	Yes	Yes

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Power Plant

Electrical Systems Analysis

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Electrical System Analysis

***What the various studies are and what answers you can expect from them*.**

Introduction

As the power requirements of DP vessels increase so does the need to provide redundancy in the electrical system design. More loads, more generators, and more redundancy mean more buses and, to predict the performance of the electrical system for all the possible configurations, more studies. The efforts required to evaluate the performance of the systems increase with their size and complexity. Among the specialized studies used to analyze electrical power systems those most frequently conducted for DP vessels fall into six broad categories:

Short Circuit Calculations,
Load Flow (Power Flow) Calculations,
Motor Starting Calculations,
Harmonics Analysis,
Transient/Dynamic (Stability) Analysis,
Coordination (Discrimination) Studies.

The results of each of these studies serve specific purposes in the planning, design, and operation of electrical power systems. All enhance the reliability of the vessel.

Relays and circuit breakers are tested and calibrated according to the coordination study. Spectrum analyzers measure the harmonics present in the power system. Power flows, voltage drops, continuous and starting currents can be measured and compared to the load flow and motor starting calculations, though for many configurations this will never actually be done. The transient performance of the system can be measured for many operating configurations to verify the calculation models, but again these tests seldom are done in a quantitative fashion. Short circuit tests are destructive, thus are not conducted in the field (at least, not on purpose).

While it is not exclusively a problem of the electrical discipline, that results of some the calculations will never be tested conclusively is reason enough for the calculations to be performed as accurately as possible.

Genesis of Electrical System Studies

Before there is an electrical system, there are mechanical loads. First the mechanical systems are defined, then the electrical loads are estimated from the individual mechanical loads. These mechanical and electrical loads are tabulated for various operating cases and totaled, providing an estimate of the overall power requirements.

Once the loads have been defined, they are grouped into “load centers” according to their physical location on the vessel. For a particular vessel classification, the requirements of the certifying agency essentially define the degree of redundancy in generation and in the supply to the load centers. Together with the load lists, these requirements form the basis of the power system design, and a rudimentary single-line diagram evolves to graphically describe the overall electrical system.

At this point in the design process, operating voltages must be selected for generation and utilization equipment. Along with the practical and economic factors, and preferences of the vessel owner or operator, equipment ratings are major considerations in the selection of voltage levels. Most non-interrupting electrical apparatus, such as transformers, motors, and generators carry a voltage rating and either a current or a power rating and are built specifically for the frequency at which they will operate. Voltage and current limitations apply to power cables, but these normally do not have frequency ratings. Devices that are used to open a circuit carry additional ratings. Starters, contactors, and some switches are rated to interrupt load current, but none are rated to interrupt faults. Circuit breakers and fuses, however, are designed to interrupt fault currents, and each carries an explicit rating which defines the current magnitude that it is capable of interrupting.

While compiling and maintaining accurate “load lists” and single line diagrams are very important throughout the development of the electrical system design, performing short circuit calculations is essential to the safe operation of the electrical system.

Short Circuit Calculations

What is a short circuit? A short circuit, or fault, is the *unconstrained* flow of electrical current. It is caused by the failure of electrical insulation or by accidentally damaging or coming into contact with electrical conductors. The extremely large currents flowing into a fault create immense amounts of heat and enormous mechanical forces, either of which can cause tremendous damage. Electrical equipment must be mechanically braced and interrupting devices must be adequately rated to safely withstand and isolate the high currents of faults; and to guarantee these results, a great deal of effort is spent on the calculations that provide the magnitudes of potential faults. During the commissioning and startup of equipment, a large part of the testing efforts are devoted to eliminating all possibilities of short circuits occurring.

Short circuit calculations are performed to determine the actual fault levels at every point in the system where an interrupting device is applied. The computed short circuit levels are compared with equipment ratings to ensure that every device in the system is applied within its fault interrupting rating.

What are the interrupting ratings? The answer depends on the standards employed. Most electrical equipment used on DP vessels is built either to ANSI/IEEE standards or to IEC standards. There are numerous differences between the design, testing, and installation requirements for the equipment built in accordance the two standards. Not only does the term “interrupting rating” have different meanings in the two different sets of standards, it also has different meanings for different voltage levels within the same set of standards. Consequently, the only way to have a valid short circuit magnitude for comparing to the equipment interrupting ratings, one must use the methods of the specific standard for the equipment being furnished.

What kinds of faults are there? Three-phase faults involve the most energy and are used to determine equipment interrupting ratings. There are phase-to-phase faults, two-phase-to-ground faults, and single-phase-to-ground faults. Single-phase-to-ground faults can occur only if the neutral of a wye connected transformer or generator provides a path for the ground fault current to flow.

What are the sources of fault current? Rotating machines: generators and motors that are directly connect to the ac system are sources of fault current. Motors connected via ac or dc drives are not considered fault current sources. What limits the fault current? System impedances: internal impedances of the sources plus the external impedances of power transformers and cables limit the fault current.

The first step in computing three-phase faults is to make an impedance diagram for all the elements in the electrical system, including all sources and system impedances. Next, an equivalent impedance is computed to represent the parallel combination of the internal impedances of generators and/or motors on a common bus. A point in the system is identified for placing a fault. Then the impedances of all the parallel between the sources and the fault are reduced to a single equivalent impedance. Finally, this single impedance is used to compute the short circuit magnitude of the three-phase fault.

The method just described for computing three-phase short circuit magnitudes is valid and correct. Unfortunately, this simple method does not account for the fact that the short circuit contributions of the sources are not constant, they decay in time from an initially high value. Fortunately, the method of computing the initial short circuit magnitude is an issue on which the many standards writing bodies around the world basically agree. Unfortunately, the rates at which the currents decay are not constant, nor are the rates the same for all sources; and the standards bodies do not agree on the analytical methods for approximating these facts.

The ANSI/IEEE methods modify the impedances of the sources before computing the "interrupting currents." IEC methods modify the individual current contributions to derive the effective "interrupting currents." Calculated by either method, the "interrupting currents" are conservative estimates for evaluating the interrupting duties of equipment built to the standards of the calculation method.

The short circuit calculations used for equipment ratings usually are not the only calculations required by the electrical system studies. For appraising equipment interrupting duties the number of on-line sources and system configurations are chosen to produce the "worst case" three-phase fault magnitudes. Even though the worst case circumstance may be physically possible to arrange, it frequently does not represent a realistic operating condition. The multiplying factors that ensure conservative calculations in the worst case may force unrealistic approximations in other cases. For example, short circuit calculations, usually without the multiplying factors, are used in coordination studies while examining the responses of protective devices when the system is lightly loaded and only one or two generators are on-line.

No matter how many conventional short circuit calculations are performed, the results do not show clearly how a particular fault varies with time or how the various currents from the contributing sources, decaying at their distinct rates, combine to form the total fault. While the conventional calculations may yield results satisfactory for most purposes, obtaining a representation of the fault currents as a function of time requires a "transient study."

Because most power systems on DP vessels are ungrounded, three-phase fault calculations are the only type necessary for system analysis. Single-phase-to-ground faults have no path for ground currents to flow, and the magnitudes of the other fault types typically are less than the three-phase values. Marine grounding practices are well beyond the scope of the present discussion, but it is important to note that as the size of the DP vessels increase so do the voltage levels, particularly for the main generation systems. At the higher voltage levels system grounding practices must be reconsidered. The practice of operating electrical systems ungrounded, which is suitable at voltages below 1000 V and marginally suitable at voltages to about 5000 V, should not be followed at higher voltage levels. These systems must be grounded in some fashion. High resistance grounding is the method most commonly employed. Magnitudes of ground fault currents must be determined for systems that are grounded in any fashion.

Load Flow Calculations

Load flow calculations are the analytical extensions of the "load lists." These calculations examine the power flow throughout the whole electrical system for both "normal" and "alternate" configurations. Voltage drops are computed from the generation bus to the load centers. Power flow through each cable and transformer is computed. The system losses are included with the loads to establish the generation levels necessary to keep the overall system in equilibrium.

System impedances are modeled the same as for the short circuit studies, but similarities between the calculations end there. Only rotating loads are used for the short circuit studies but all loads, heaters, lighting, hotel, propulsion, drilling, etc., are considered in the load flow calculations. For on-line motors, the real (kW) and reactive (kVAR) power levels at their operating loads are used instead of their impedances. Generators are represented in load flow calculations either as sources with fixed outputs or as “infinite” sources capable of supplying whatever power is necessary to maintain the voltage at the generation bus.

The results of these calculations may be used to schedule generators for various operating cases. Overloaded cables and transformers and excessive voltage drops are identified easily, advancing the formulation of remedial strategies.

Motor starting calculations, harmonics analysis, and transient analysis all begin with a load flow calculation, in one form or another.

Motor Starting Calculations

On DP vessels, motor starting calculations occasionally are performed for motors applied at the voltage levels of the emergency and auxiliary systems, but seldom are necessary for motors applied at the voltage level the main generation system. Motor starting studies are performed in cases where a motor is relatively large with respect to the available generation or where it is relatively large with respect to the kVA rating of a transformer. In both cases, the critical relative size occurs where the nominal motor hp is 20% or more of the nominal kVA of the source, either generator or transformer.

Three different types of studies are included in the category of “motor starting calculations.” Measured by the amount of additional data required to perform the studies, the simplest type of calculation is determining the initial voltage drops throughout the system at the instant a motor is started. This calculation is a minor variation of the load flow calculations. The only additional information required to perform this calculation is motor nameplate data. The next simplest type of calculation examines motor and system voltages during the interval of starting and accelerating a motor. Performing this type of study requires additional information about both the motor and load, and about the voltage regulators and exciters of the generators, if these are to be included. The third type of calculation is performed with “transient analysis” methods and requires extensive data, not only about the motor and load, but also about the generators, their prime movers and governors, and other large motors in the system. Results of this study show both the voltage and frequency profiles at selected locations in the system while the motor is being started and accelerated.

Harmonics Analysis

Electrical systems of DP vessels are rich in harmonics.

What are harmonics? These are the voltages and currents in the electrical system which have frequencies other than the rated frequency of either 50 Hz or 60 Hz . Harmonics are expressed as multiples of the fundamental frequency. For a 60 Hz system, the 5th harmonic is 300 Hz, the 7th is 420 Hz, ...

What causes harmonics? Switching the solid state devices in ac and dc drives are the main causes of harmonics. On DP vessels, the chief sources of harmonics are the thruster drives, ac or dc. Where drilling is involved, the predominantly dc drives of the drilling loads also are major contributors to the harmonic spectrum.

What harm do power system harmonics do? Harmonics distort the sinusoidal character of the ac waveform. They cause overvoltages on the power system. They increase the losses of the power system. Harmonics cause heating in motors, generators, and transformers which result in reduced capacity, loss of service life, and sometimes total failure of the equipment. They cause protective devices to fail and affect the performance of electronic equipment.

What are the limits for harmonics? Most standards, rules, and guidelines limit the total harmonic distortion of the voltage waveform to 10% on buses that serve only power conversion equipment and to 5% on buses serving conventional loads. Total harmonic distortion, THD, is the rms value of all harmonics present in the waveform expressed in percent of the fundamental frequency.

What can be done about harmonic problems? Filters can be designed to minimize the effects of the harmonics. These are arrangements of inductors, capacitors, and sometimes resistors that are tuned for the troublesome harmonics. The filters provide low impedance paths for the flow of the harmonic currents, diverting these currents from other equipment.

Harmonics analysis is a specialized type of load flow calculation. Models for the internal impedances of the generators are added to the network of system impedances. Drives are modeled as sources of harmonic currents. Revising system reactances for the different frequencies, load flow calculations are run for the frequencies of interest, beginning with the fundamental. The results of the load flow computations for all frequencies are combined into a family of outputs that define the harmonic spectrums of the voltages and/or currents at the points of interest.

Harmonics are not constant in the power system, they vary with the loading of individual drives, the configuration of the system, and the number of on-line generators. Harmonic analysis is used to quantify the harmonic voltages and currents on the system for various configurations and operating conditions and to evaluate the affects of filters on the system harmonics.

It is common practice to apply filters to the generation buses. Difficulties in determining the optimum sizes for the filters increase with the number of tie breakers used in the generation bus. Filters are sized and tuned for worst case harmonics conditions, but their affects on the system line also must be examined for light load conditions when few generators are on-line. In these cases, to prevent possible overvoltages due to the capacitors, the filters may have to be disconnected from the system.

Transient/Dynamic (Stability) Analysis

Depending on the facet of the system being examined, the analysis method is called by different names. The studies are called “transient” because they investigate abnormal incidences that occur for a short time interval. They are called “dynamic” because they investigate the balance between mechanical and electrical energy and the forces that act to keep the energy systems in equilibrium, or to drive them apart. They are called “stability” when the investigation is whether or not synchronous machines will remain in synchronism with one another.

By whichever name the study is called, it refers to the voltage and frequency responses with respect to time of system elements following a disturbance. The disturbance may be the incidence of a short circuit, clearing the fault, the sudden application of a load, the sudden loss of load or generator, opening a tie breaker, etc.

A substantial amount of data is necessary to adequately model the mechanical and electrical systems and sub-systems. But once the data is compiled and the model parameters determined, significant information about the performance of a system can be determined with the studies. The studies compute how the power, voltage, and frequency of major machines oscillate with respect to each other, through what extremes the oscillations travel, and the duration of the oscillations.

Transient studies are a series of load flow calculations performed sequentially. First, a steady-state solution is obtained for the conditions of the system prior to the disturbance. The disturbance will add or remove either mechanical or electrical power. When this change is incorporated into the model, the initial responses of the system parameters are calculated. The process is repeated, time is advanced by a small increment, then small changes in the mechanical and electrical systems also are computed, and a new solution is obtained for the power flow, until system equilibrium is reached (or until it goes unstable).

These studies are particularly useful for DP vessels to analyze the “what ifs” for likely configurations and operating conditions. Remedial decisions can be made in advance of a potential problem to avoid compromising the reliability of the electrical system. The calculations and decisions based on them can be used as inputs to power management systems.

Coordination (Discrimination) Studies

Of all the studies performed on electrical systems, coordination studies are the most subjective. The various standards bodies have requirements that define the extent of protection for major equipment, generators, motors, cables, and transformers. Although the degree of protection differs slightly among the standards, the intent of the various standards are similar enough that good engineering practices and common sense usually will satisfy the requirements.

A coordination study includes examining the settings for voltage, frequency and power relays, but the bulk of the coordination efforts are devoted to the settings of overcurrent devices. The objective of a coordination study is to specify settings for protective devices that (1) provide overload protection for the circuit to which it is applied and (2) ensure that faults are cleared as rapidly as possible by the nearest device upstream from the fault. Settings are determined for every overcurrent device in the system, beginning with the devices that serve the loads and stepping sequentially to the next upstream devices until the protective devices of the generators are reached. Time margins are specified between each step to give a downstream device time to open the circuit before an upstream device operates.

Protective devices are set to be selective at the maximum short circuit levels that each breaker must interrupt, that is when all generators and motors are on-line. These settings also must be examined for cases where the available short circuit currents are less than maximum.

Selectivity between overcurrent devices is demonstrated graphically. To show the coordination among a family of devices simultaneously, the time-current characteristic of each device in series is plotted on a common log-log graph. Then the settings of the protective devices are manipulated so that circuit protection is maximized, clearing times are minimized, and suitable time margins between characteristics are preserved. How these objectives are best satisfied is subjective, there may be no “best solution.” For some combinations of protective devices, where dissimilar characteristics of the curve family prevent achieving complete selectivity, or where complete selectivity would require excessively long clearing times, coordination compromises always favor personnel and equipment protection.

A situation for which obtaining selectivity is very difficult, and one that sometimes can not be avoided, is where a several devices in series are applied to circuits having nearly the same kVA ratings. Another situation where a breach of coordination can occur is for alternate system configurations where the desired settings for a protective device are in conflict with the settings required by the normal configuration.

Coordination and selectivity between overcurrent devices usually are possible in the normal configurations of a well designed system. Even the most difficult of the coordination problems can be avoided at the design stage by judicious choice of equipment ratings and/or protective devices.

Summary

Single line diagrams and load lists provided the baseline references for electrical system studies. These are the two most important documents (followed by cable schedules and equipment lists) for describing the configuration and the loads of an electrical system. They should be kept up to date and as accurate as possible.

Short circuit calculations are *essential* to safe operation of the electrical system. The results of these calculations are used to ensure that interrupting devices and equipment ratings are correct for their applications.

Load flow studies compute the operating voltages of all buses and the flow of real and reactive power throughout the system. They are used for determining generation requirements of various load conditions, for determining or verifying ratings of circuit components, and are particularly useful for analyzing alternate configurations.

Motor starting studies ensure the successful starting of large motors without causing excessively low voltages elsewhere in the system.

Harmonics analysis is used to evaluate the potential of a system to produce harmful voltage and current harmonics. These studies are used to design and locate filters that prevent equipment damage due to harmonics.

Transient analysis methods are used to examine system performance when the variations with time are required for power, voltage, and frequency parameters; and when the conventional short circuit, load flow, or motor starting calculations can not provide information in sufficient detail. These studies require the most data and, because of the many types of mechanical and electrical sub-systems involved, are the most difficult to model. But these studies provide the most information about the manner in which the system recovers from a disturbance.

Coordination studies are done to limit the time that equipment can be overloaded, to minimize the time required to isolate and remove a fault, and to minimize the portion of the system disrupted by removing an overcurrent condition. Although it is the most subjective of the electrical system studies, when done correctly the coordination study greatly enhances system safety and reliability.