SHIP POWER PLANT – SAFETY DESIGN

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Abstract

Safety and survival at sea are the consequence of a detailed and diverse range of factors which, in addition to the human element, include the tasks being undertaken, the environment in which they are being undertaken, and the available equipment. One of the factors which help determines the human element in safety and survival at sea is the experience of the individual. So the training appropriate actions to take in emergency can improve safety and survival during emergency.

With the aspect of the developing of technology of the maritime shipbuilding industry crews who serve on board modern ships must have technical knowledge of highest standards to enable them to operate complicated machinery correctly. They must be able to operate their ship efficiently and safely. In recent years, advanced functions have been added to power management system to be able to control the power generation and consumption by optimizing the instantaneous power flow and use. The point is also on the design process which mainly depends on skills and possibilities of design engineers. As a rule, they specializing in designing different design properties (reliability, manufacturability, etc.), have applied design solutions proved in practice or have presented their proposals during design reviews.

The paper deals with computer – aided system supporting design of the most dangerous procedure in ship power plant from a safety point of view.

1. Introduction

Ships are specific technical systems with possible types of hazards such as fire, explosion, accidents, floating etc. Safety must be designed into a system from the beginning, which requires that the designers have the information necessary to accomplish that goal. The most dangerous ship spaces are their power plants. The power plants on the ship are very unsafe for operators because the ship machinery is designed to ensure the maximum safety for its operators.

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The main different between the marine power system and a land based system is the fact that the marine power system is an isolated system with short distance from generated power to the consumers, in contrast to what is normal in land-based systems where there can be hundreds of kilometres between the power generation and the load, with long transmission lines and several voltage transformations between them. The amount of installed power in vessels may be high and this gives special challenges for the engineering of such systems. High short circuit levels and forces must be dealt with in a safe manner. The control system in a land-based electrical power system is divided in several separated sub-systems, while in a vessel; there are possibilities for much tighter integration and coordination. The design of power, propulsion and control systems for a vessel have undergone significant changes and advances over a relatively recent period of time. Because of the rapidly expanding capabilities of computers, microprocessors and communications networks, the integration of systems which were traditionally separate, stand alone systems is now not only feasible, but fast becoming industry standards. The increasing demand for redundant propulsion and DP class 2 and class 3 vessels requires system redundancy with physical separation. The interconnections of the diverse systems on a vessel have become increasingly complex, making the design, engineering and building of a vessel a more integrated effort.

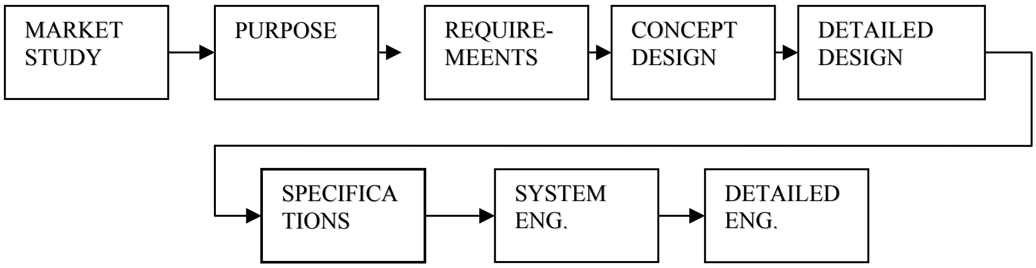
In a system of electrical power installations, vessel and process automation system, and positioning system, the various parts of the automation system controls their parts of the power system, e.g. the dynamic positioning system controls the thrusters drives, the off-loading control system use cargo pump drives, the process control system interacts with compressors and cooling/heating systems etc. The interconnecting point for all installed power equipment is the power distribution system. By starting and inrush transients, load variations, and network disturbances from harmonic effects the load and generators are interacting and influencing each other. Optimum operation and control of the power system is essential for safe operation with a minimum of fuel consumption. As it is the energy control system (energy, and power management system), which monitors and has the overall control functionality of the power system, it will be the integrating element in a totally integrated power, automation and positioning system.

The purpose of the Power Management System (PMS) is to ensure that there is sufficient available power for the actual operating condition. This is obtained by monitoring the load and status of the generator sets and the power system. If the available power becomes too small, either due to increased load or fault in a running generator set, the PMS will automatically start the next generator set in the start sequence. A power management system can also have extended functionality by monitoring and control of the energy flow in a way that utilizes the installed and running equipment with optimum fuel efficiency. Such systems can be called Energy Management System (EMS).

Blackout of the power generating system is the most severe fault that can happen in an electric propulsion system. Various mechanisms to avoid blackout are linked to the power management system, such as the auto start/stop functions, reduction of propulsion and other loads, or shedding of non-critical loads.

The amount of installed power gives special challenges for the engineering of such system. The design and engineering phase can be illustrated by Fig. 1. Before the vessel concept designed starts a market assessment based purpose and requirement specification for the vessel should be made as the basis for the design work.

Figure 1: Stages in marine engineering work



The design phase will result in a set off technical specifications for the vessel, which is the basis for the further engineering work. Another phases-engineering consist of several analytical and numerical calculations. Standard calculations in the second phases are: load flow calculation, short circuit calculations, ground fault calculations, relay coordination study, harmonic analyses, and voltage drop calculation of inrush transformers and starting motors. Depend on system configuration and vessel application also can be required transient analysis of network behaviour after disturbance (short circuit) and reliability or failure mode analysis.

2. Insufficient power

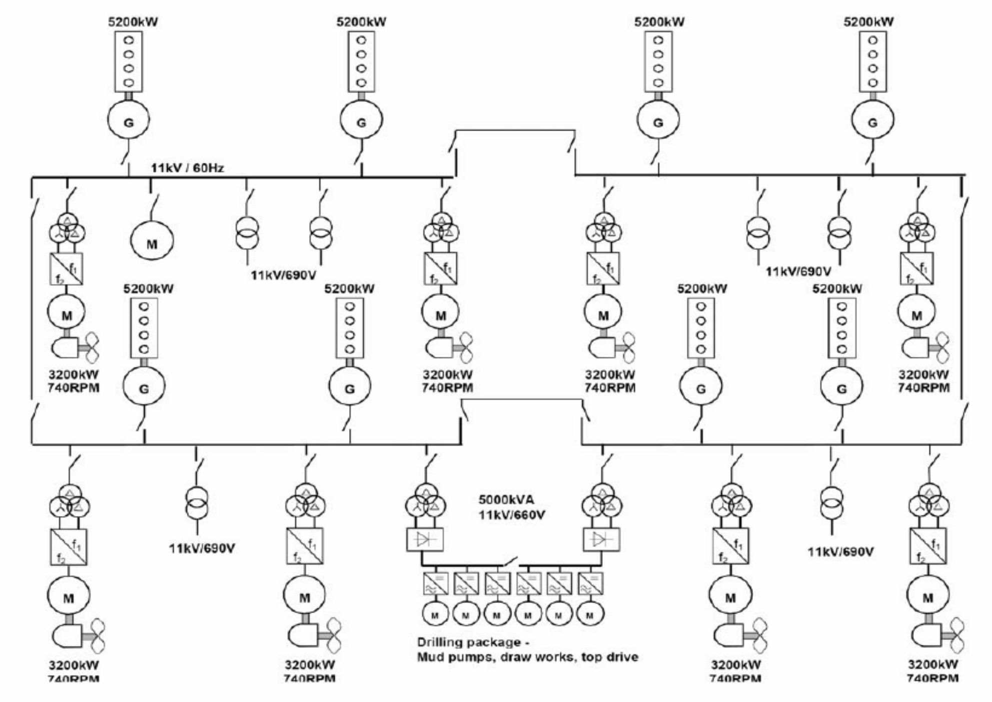
Designing the electric power system of a ship means calculation of the necessary power and number of generators, as well as loading cables, breakers, transformers and other critical components, both under normal load and short circuit conditions. Analyses of transient conditions are often limited to simplified calculations of start-up of large motors, i.e. motors with a rating of more than about 10% of the rating of the generators running. In many cases these calculations will be sufficient. However, in systems with high generating power, large asynchronous motors, or large static converter loads, this will not be enough. For such systems it would be of current interest to carry out more analyses e.g. of transient conditions during faults and start-up of motors, as well as analyses of harmonics when static converter load is present.

This work is carried out to improve the basis for designing electric power systems for ships, and to give an overview of the different tasks during the design stages. The emphasis is on establishing routines for examination of electric power systems for ships, with respect to establishing general guidelines and a presentation of routines in a manual for the designing of the electric power systems of ships.

Insufficient power can be preceded by such alarms as:
- Insufficient thrust;
- Heading out of limits;
- Position out of limits;
- Blackout –if the all power is lost.

However if there is a power reduction then a blackout can be avoided but not a loss of position, a drift off. The alarms that accompany a reduction or chop in power are typically, preferential trips, pitch or speed reduction of thrusters and phase back if the dynamic position vessel was drilling for example.

Figure 2: Complex power plant system



Causes of insufficient power' alarms:

- Design
- Equipment failure
- Control fault
- Weather
- Operator error.

2.1. Design of Power Plant

That means the size and numbers of power generators were initially insufficient or, have become insufficient as the vessel's work changed or the client expectations increased. In design of power plant causes of insufficient power can be:

- incorrect power balance;
- incorrect transformer capacity;
- too few generators;
- uneven number of generators per switchboard;
- speed of response of generators too slow (different prime movers and types).

An incorrect power balance can be a basic error but it is more likely the result of growth of the operational requirements as the vessel is marketed after the long lead items like generators and thrusters have been ordered. Another possibility is that the location(s) planned, were more benign in climate than the ones where the vessel is presently working. The other problem is how to measure the diversification of consumers and account for reliability/availability. Clearly there are different margins applicable to a vessel that is working 364 days per year and one that anticipates 200 days per year (as opposed to on passage and in port).

Transformers (usually the HV to 440V transformers), are best sized with ample capacity so the normal load is 50%. This allows for growth and some flexibility if the cooling system fails.

The number of diesel generators is usually a function of space and cost and this can result in four large machines. If the parameters had been reliability and uptime the results may have been six or eight diesel generators. While more machines will increase capex and maintenance time, it can reduce running hours and increase the average loading. Only even numbers are mentioned because an uneven number of machines are a problem if the basic concept is for two main switchboards. Of course one engine could be designed to power either, but this solution is the start of other problems with the design.

The type of engine is also important because when there is insufficient power, the time for a machine to accelerate to take the new load is crucial to the avoidance of blackout and/or the speed of blackout recovery. The larger and slower engine can be cheaper but a fast PMS does not keep a slow engine on line when power is suddenly lost from the switchboard.

2.2. Equipment failure -single point failure

That mean that on experiencing a 'single point' failure the insufficient power alarm occurs because not enough power reserve was on time initially or the failure was not foreseen:

- Generation Fault
- Large Consumer Fault
- Breaker Fault
- Bus Bar Fault
- Fuel Oil Pump Fault.

The failure of one generator should not cause an insufficient power alarm unless the margin on line was initially too low or it co-insides with a peak loading. If the generator fault is a control problem, the effect can be different and this is discussed later. Similarly a fault on a large consumer should cause it to trip and no more problems arise. If, however the fault is large and the tripping slow, under voltage trips can create an expanding problem and insufficient power result. This leads to the next point, a breaker fault. The worst case is when it fails to trip when it should. This can be counted as two faults; one, the fault that should initiate the trip, and two, the fault in that the breaker fails to trip. This is a rare event but it has happened. A bus bar fault is even rarer; they have happened but mainly as a result of a mistake after work has been carried out. If there is a fault (short circuit) on the main HV (**H**igh **V**oltage) bus with the bus ties closed, a blackout is highly likely. If the bus ties are open, there is a chance that there is still a blackout; it depends on the set up of all consumers and the PMS.

The final equipment failure is illustrated in a fuel oil pump. In itself it is not a major item of equipment, but its effect can be that the diesel generator or generators it is supporting cannot deliver the required power and the power management system is unaware of this situation until the reserve power protection works.

2.3. Control fault

A control fault could be hardware i.e. equipment, but this group is designed to cover more software issues associated with the vessel power management and DP Control Systems. An operator intervention can cause a sudden thrust demand and insufficient power alarm:

- Engine Governor
- Speed Control
- AVR (Automatic Voltage Control)
- Control (dc) Power
- PMS
- DP Control
- Thruster Control etc.

It is in the area of control that the insufficient power alarm is likely to cause the most concern. This is because several faults can have similar alarms and end results and on the modern DP Vessel there are so many alarms that those that start the sequence are difficult to separate quickly from those that is the consequence of the first. The best failure mode effect for a diesel generators governor depends on the system.

Some electronic governors on some failures cause the engine to reduce speed and trip. Others are set up for the mechanical governors to take over in droop mode. Irrespective of the care and precautions taken, it is possible for one diesel engine to take all the load it can and risk all or part of the power plant. IMCA (International Marine Contractors Association) data shows that this is a failure mode that must be seriously considered. It is also this and similar failure modes like an AVR fault or a speed control fault (pick up or cable) that make a closed bus arrangement more robust than an open bus arrangement.

The powering of the breakers, sensors, relays and logic for the control of power and avoidance of insufficient power alarms is usually 24V and 110V DC. Their systems are generally very reliable but if they fail then the effects are fast and very difficult to recover from. With the DP control systems, it is now normal for each to have a dedicated UPS. This is the result of experience. Normally one would consider the loss of the charger supply and the loss of the battery back up as two failures. There have been two many of them to regard this as two failures. One must consider the failure of the output itself. One may conclude that if the vessel has good procedures and a good PMS (power management system); there should not be many occasions when there is an insufficient power alarm. This is reasonably true if the demand for power changes slowly, the system is set up correctly and the PMS has the data it needs. The DP control system can provide an insufficient power alarm because it has simply lost data i.e. it has no generator information. It can also generate these alarms from a sudden thrust demand or unstable positioning caused by a multitude of possibilities. On some occasions the fact that there is insufficient power on line can limit the drive off or excursion but mostly the effects are bad and a serious problem can develop if the generators cannot actually deliver their rated power.

Thruster control is another area where insufficient power alarms can be generated. The most likely is when one thruster provides high (unwanted) thrust and others have to compensate. The other occasion when insufficient power frequently appears on the DP alarm print out is when the DPO gives up with the DP control system and moves to joystick control.

2.4. Weather

A similar sequence of events can occur if the weather suddenly changes in speed or, for a monohulled vessel, direction:

- Slowly Deteriorating
- Current
- Solutions
- Squalls
- Rapid Wind Increase.

Deteriorating weather should never cause an insufficient power alarm by itself, because additional power should have been on line in advance of the requirement. However some PMSs are set so that an alarm for insufficient power may come at the same time that a generator starts. The risk from this approach is that the incoming machine does not solve the problem, but makes it critical. It is uncommon for this to happen but there are enough occasions to change the procedures on some vessels.

Currents do not change rapidly, unless they are tidal and then one would expect more power to be on line before an alarm. The classic exception is when the tide is changing and the vessel was head to the current and during the change a 1 knot current comes on the bean of the vessel. The DP control system would not respond until perhaps a 4 or 5m excursion had been reached (dead band) and then apply substantial thrust and cause insufficient thrust and insufficient power alarms. The quick current or fast integral features of DP control system helps if the operator selects them in good time. If the sudden current change is an internal wave or solution, then the position loss can be much more than a few meters and cause some considerable duration of an insufficient power alarm.

The most common weather cause of a DP incident (loss of position) with or without a power alarm is a wind squall. However, given the frequency of such events the numbers of times they cause a serious DP problem are few.
For an accommodation unit that is gangway connected a squall can cause auto lift of the gangway, but this type of excursion is relatively small for most vessels working in open or deep water.

The most dramatic weather associated DP problem is rapid wind increase when the wind suddenly hits a monohulled vessel on the beam and increases from practically calm to 40 knots in a minute or two. A monohulled vessel may not have time to change heading before the position loss is too great.

2.5. Operator error

And finally operator error, which really covers direct mistakes rather than the mistakes associated with all the above. It is not difficult to make every incident human failure.
Even being struck by lightning in a thunderstorm can be blamed on human error, for not installing an adequate lightning conductor:

- DG Trip

- F.O Valve Closed
- Stopped Wrong DG
- Opened Bus Tie
- Closed Breaker
- Maintenance

The list above illustrates some of the many mistakes made by operators that have directly and immediately caused insufficient power alarms. There are other categories of operator error that could be included like software bugs, poor procedures, no, or no adequate check lists etc, etc.

We can make conclusion that:

- Insufficient power alarms – will happen but they are not necessarily critical
- Blackouts of all main power – can happen but they are not necessarily critical
- Failure to recover after blackout – is critical and should not happen

3. Modelling

To perform analyses suitable computer models need to be defined. These models must be able cover transient conditions and stability studies, as well as steady-state conditions. The electric power system, including the prime movers and generators with regulators, transformers, cables and the main motor drives etc. need to be modelled, dependent on the purpose and method of the analyses.

Calculations on onshore power systems are often carried out using simplified network models. These simplifications are not always applicable for ship power systems. Analyses of such systems may therefore require other models. In this work well known models have been used for electrical and mechanical components, as far as possible. This applies to models both for steady-state and transient conditions. Parameters are, as far as possible, obtained from the suppliers, including structure and parameters for the models of the voltage controllers, governors and prime movers. When parameters are missing, the models are tuned according to measurement.

3.1. Analyses of steady-state conditions

Analyses of steady-state conditions cover calculations of load balance and load flow, steady state short circuit calculations and analyses of harmonics. Reliability evaluations and economical conditions may also be counted in here. Analyses of steady-state conditions primarily determine the thermal rating of the system, and may often be carried out as simplified calculations. Quasi steady-state analyses may also give the mechanical stresses during short circuit conditions, as well as simplified considerations of conditions during start-ups of asynchronous motors. Analyses of steady-state conditions also make the basis for transient calculations, as they describe the pre-disturbance conditions. Reliability evaluations are useful e.g. for comparing different concepts, while economical calculations in most cases determine the choice of concept.

3.2 Analyses of transient conditions and stability calculations

Analyses of transient conditions and stability calculations cover motor start-up and shutdown, generator tripping, temporary short circuit situations, crash stop manoeuvre and other load variations, as well as cascading faults. Analyses of transient conditions are primarily used for evaluation of stability conditions, in addition to more accurate calculations of conditions during start ups of motors and for mechanical rating during short circuit conditions.

3.3 Design guidelines

Based on the results from the analyses of the example networks as well as general observations this work proposes a classification of the different ship power system, describes the analyses of current interest, and gives an overview of the necessary analyses for the different classes of power systems at the different stages of design.

4 Communication

The preparation of documentation and procedures is more than just the production of the obligatory shelf of paper to comply with various requirements. It is integral to any installation information management and communications systems. A well-defined and implemented information management system has the potential to increase productivity and safety, and conversely bad systems will prove costly to all operators. Ensuring that the documentation that forms the template for many parts of an operation is concise, accurate and relevant will pay dividends in many areas that start with operations, and then encompass safety and training. The challenge is to develop a system of information management and communications that works at all levels. The documentation is the starting point.

Successful operation of control systems require more than knowledge and experience. Human factors will always play a major role in the success or failure of any DP operation. We must not only recognize that these factors exist, but train operators in how to deal with them.

5. Conclusion

The main contributions can be summarized as follows:

- A classification of different ship power systems is proposed. The classification is based on criteria that are easy to identify, and the target is to make the design procedures identical for power systems within the same class.
- The different analyses of current interest are described for power systems with local generation. This also includes comments to the different rules and regulations that apply, as well as examples of suitable computer tools.
- A systematization of the necessary analyses for designing the different classes of power systems in the different stages of design is proposed.
- Use of computer programs for analyses of steady-state conditions, transient conditions and stability calculations in ship power systems is tested for the example networks. The results are compared to measurements and simplified calculations, as well as being evaluated concerning uncertainty in input parameters and computer models.
- Routines are proposed for examination of electric power systems for ships with respect to a later establishing of general guidelines and a presentation of routines in a manual for designing ship electric power systems.

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Anita Gudelj was born in Split, Croatia (1970). She received her B.S. degree in mathematics and computer science (1993) from University of Split, Faculty of Mathematics. Since 2006 she is a senior lecture at the Maritime Faculty University of Split. Also, she received the M.Sc degree in information science from Faculty of Organization and Informatics, Varaždin, Croatia (2000). Her postgraduate research was "Design and Implementation of Temporal Database". Her research interests include database design, genetic algorithms and Petri nets. Her main activity is focused on performance modeling of automated transportation systems, vehicle dynamics and control, and optimization. She is the author and co-author of several research papers in these areas. She is also a member of several national and international societies (e.g. IEEE, INTERNATIONALSTARS…)

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