SAFE OPERATION OF THE ELECTRICAL POWER SYSTEM

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Abstract

Maritime electrical systems are autonomous systems. The prime movers including diesel engines, gas/steam turbines, are integral parts of the systems. The power consumers are large compared with the total capacity of the system, as for example thrusters and propulsion systems for dynamic positition operated vessels, drilling systems etc. The complexity of vessels such as cruise vessels, ice breakers or vessels where much manoeuvring is required (frequent change in propulsion load) requires dependable electrical power for operation, integrity of the well and safety – of both the installation and its personnel.
With the increasing use of +450 V with onboard equipment the special course (High Voltage)/lecture or simulator is aimed at engineers/personnel (electrical or non-electrical) required to carry out restricted switching duties and includes preparation procedures for using HV systems safely.
The simulator/course was identified as the best choice to create the competent ship operators within shortest time. Specific training objectives include the overall training objective of specific model is:

- To understand the total plant operation, familiarisation with electric plant, understand the need for high voltage levels in a large power system etc.
- To reduce the risk of human error in the operation and maintenance of marine equipment.

1. Introduction

Large power equipment and processes utilise high forces. Electrical, mechanical, thermal and chemical changes produce the desired operation. Very high values of voltage, current, power, temperature, force, pressure etc. create the possibility of danger in an engineering system.
The electrical power system on board ship is designed to provide a secure supply to all loads with adequate built-in protection for the equipment and operating personal. During its working life the equipment must be continuously monitored and correctly maintained by professionally qualified personal who understand its operation and safety requirements. For ships with large electrical power demand it is necessary to utilize the benefits of a high voltage installation. For marine practice that is >1000 V. Working at the high voltage significantly reduces the relative overall size and weight of electrical power equipment.

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Voltage and frequency can be chosen in accordance with IEC 60038. The preferred values for ship supply systems are in Table 1.

Table 1: AC three-phase systems having nominal voltage above 1kV and up including 15 kV

Nominal system voltage [kV]	Nominal Frequency [Hz]	Highest voltage for equipment [kV]
3	50 or 60	3,6
3,3		3,6
6		7,2
6,6		7,2
10		12
11		12
15		17,5
*The values are voltages between phases		

Year by year the maritime shipbuilding industry develops more and more high technologically vessels. Crews who serve on board modern ships have technical knowledge of highest standards to enable them to operate complicated machinery correctly. They must be able to operate their ships efficiently and safely. Marine engineers, nowadays, should have a wide range of professional knowledge and skills: from work with a hand tools to the use of computer technologies, providing both watch-keeping and unattended machinery space. Interactive simulators in comparison with educational facilities equipped with only real on-board hardware, are obviously becoming a powerful tool to achieve the competence of crews defined with STCW 95 convention.

2. Power system

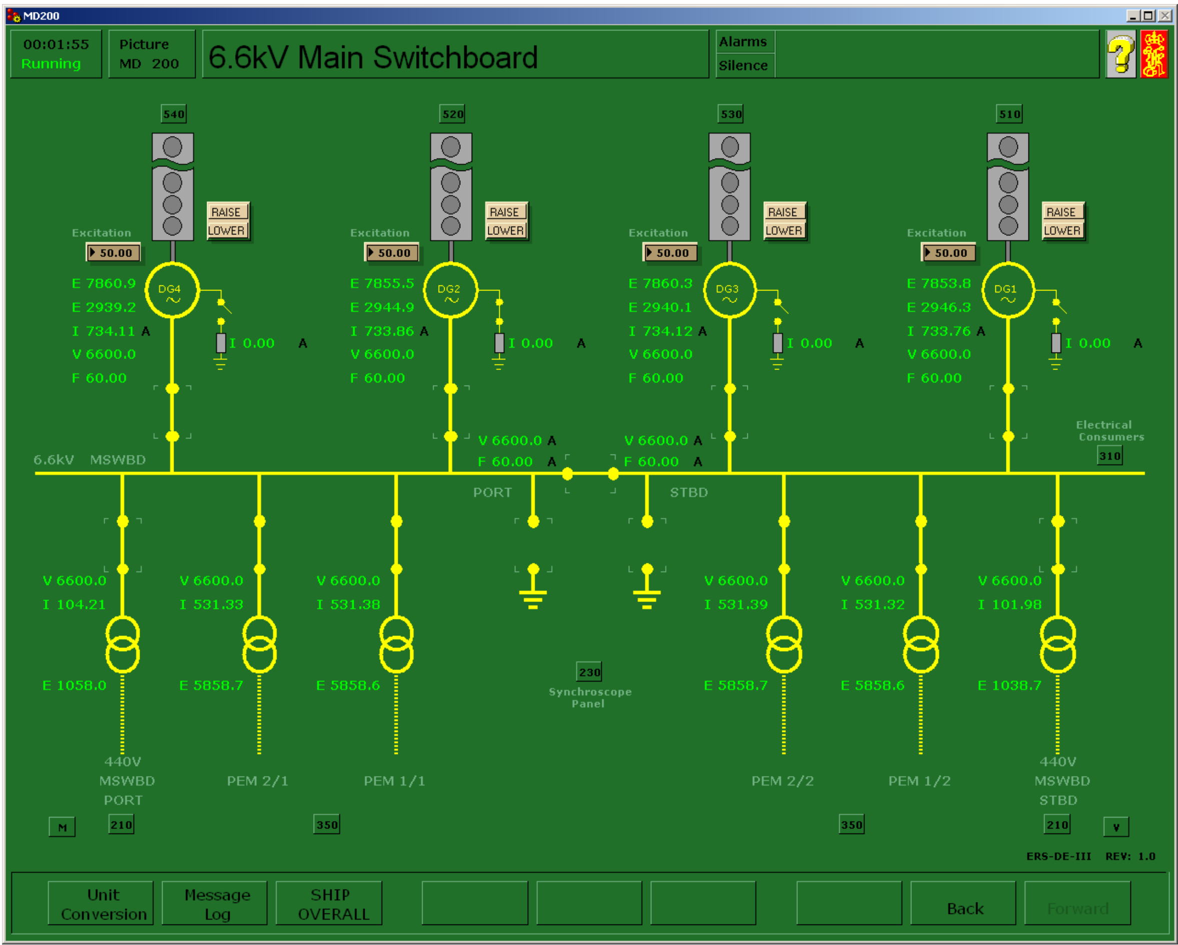
The function of ship's electrical distribution system is to safely convey the generated electrical power to every item of consumer equipment connected to it.
The power generation and distribution system is divided into the following main parts:

- Power plant with prime mover and generator;
- High voltage switchboards and bus tie breakers or bus transfers for cross feeding between switchboards;
- Voltage conditioners or filters for reducing harmonic interference;
- Transformers for feeding of alternate voltage levels;
- Low voltage switchboards and motor control centres;
- Rotating converters for frequency conversion and clean power supply;
- Uninterruptible power supply of sensitive equipment and automation systems.

The electric power plant consists of turbine or diesel engine driven generators. Due to requirements of local control and fast response times, the speed and voltage regulators are dedicated systems that are located near the power plant. By rules and regulations, the vessels must be equipped with emergency generators. A recent trend is to certify main machinery and generators for emergency power supply giving savings in cost and even more important, space.
The generating power and number of units are to be selected from maximum load conditions and redundancy requirements. The operational profile should also be regarded in order to avoid non-optimal low-load operation of engines.
The power distribution system consists of main switchboard, usually split in two, three, or four sections (depend of vessels type). Safety is an issue of concern when yards and ship owner's changes from low to higher voltages, often leading to a misunderstanding effort to keep voltages

as low as possible. In the context of safety, it should be regarded that high voltage switchboards is designed to prevent personnel to get contact with conductors, even in maintenance of the switch gears. The normal and fault currents are similarly smaller, giving less forces on the conductors and cables during e.g. short circuit. Although short circuits inside the switchboards are extremely rare, arc-proof design (IEC 298-3) should be standard in order to prevent person injury and limit the equipment damages if worst case should occur.

Figure 1: 6,6 kV Main Switchboard [KONGSBERG, 2003]



2.1 Integrated solution

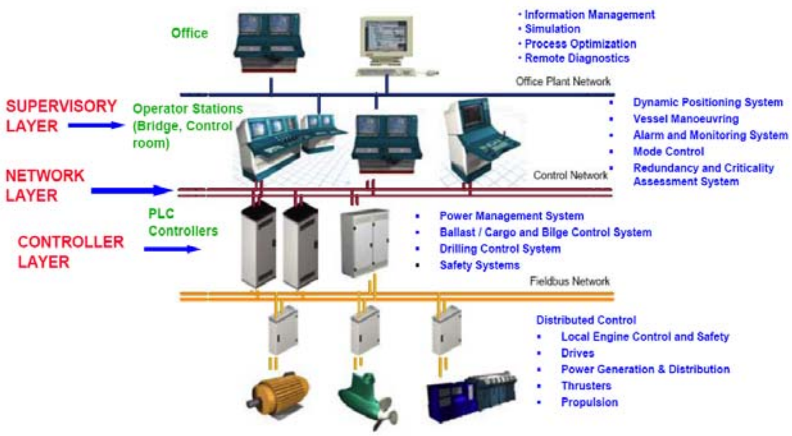
In the operation of vessel, there are several sub-systems working together, and the merging of software and hardware platforms in automation systems has enabled totally integrated automation system comprising: Propulsion and thrusters control, Dynamic positioning / Position mooring, Power management system, Vessel automation system, Cargo control, Ballast control, Process automation system, Emergency shutdown system, Fire and gas detection system, Off-loading control system, Drilling control system, HVAC control system….With today's standardization on communication in automation systems, it is relatively easy to connect various sub-systems into network communication system. There are three levels (Figure 2.):

- Real time field bus network communication on low level between devices and controllers;
- Real time control network connecting controllers and operator stations;
- Office plant network – various office systems and information management systems which is opens up for satellite communication to land offices at ship operators.

2.2. Power Management System

Power Management is defined as control of the power generation and distribution system to assure adequate and reliable electrical power is continuously available for the thrusters, drilling, marine, and hotel loads. The power management system starts/stops, and synchronizes the main generator sets in response to the system loading with the objective of preventing blackouts while minimizing the number of on-line generator sets. The fast phase back or "frequency spill over" should be an integral part of the PMS in any newly designed system. Proper operation of the power management system on a dynamic positioned vessel is essential to keeping the dynamic positioned vessel on location without disconnect and to assure the safe, reliable, and economical operation of the power plant. For these reasons, the power management system on such vessel must be understandable, reliable, and effective for operators, crew, and supervisors. The power management system must keep operations personnel informed about the condition of the electrical power system and should act promptly and effectively to prevent or correct situations which may lead to an electrical blackout. To prevent blackouts, it is important to understand how they may occur.

Figure 2: Integrated Control System Hierarchy [SØRENSEN, 2005]



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 thruster drives, the off-loading control system uses 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. The power management's main functions can be grouped in: power generation management, load management, distribution management,

The Power Management System includes /regulates the following functions and equipment:

Power Generation Management:

- Number of engines on line (starting of engines and the starting process, synchronization of engine with bus, stopping of engines, monitoring engine loads to automatically start or stop engines);
- Load sharing between engines (real power , reactive power , alternative loading);
- Protection of engines from damage (engine manufacturer supplied controls, PMS response to engine sensors);
- Engine Auxiliary systems (fuel, cooling water, air supply).

Load Management:

- Propulsion devices;
- Application Loads – Drilling systems, Cranes or Pipe Laying equipment;
- Primary Vessel Loads (HVAC system, lighting, communications, general ship services, auxiliary systems for propulsion and power generation);
- Controllers for the System Loads (DP System, drilling system, load switching to add or remove non-critical loads.

Power Distribution Management:

- Main Power System configuration – Bus Tie Breakers;
- Ship's Distribution Systems;
- Emergency Load Distribution;
- Power Sources for PMS and related system controllers.

While there are many choices that must be selected to perform the design function, the choices are generally not between a "right" and "wrong" method of implementation, but choices that subsequently require further selections to achieve a properly designed system. These subsequent choices may not be wrong in and of themselves, but a selection may be wrong because of earlier selections. Some of the choices are created by the design of the vessel itself, and others are made in the process of defining and designing the systems in that vessel.

2. 3. Example of Fault Situations

There are several possible faults in a power system, and the main task for the operator and control systems is to ensure that a fault in the system does not grow to the most serious fault, a total blackout. The most frequently occurring fault in a power system is sudden trip of a connected generator. There are several reasons for a generator trip to occur, and the consequence is that this will give a sudden increase in the load of the remaining generators. Hence, if the remaining generators are overloaded and no action is taken to reduce the generator load, the power system will experience a blackout.

In case of a generator trip, the main problem is the time aspect. In case of few generators running, a generator trip may result in generator load in the range of 140 – 160%, and thus the load must be reduced very fast to avoid trip of the remaining generators.

Fault in installed equipment is also an error that occurs from time to time in electrical power system. It the error occurring is an electrical short circuit; the voltage will immediately drop to zero if no actions are taken. Hence if no proper action is taken when a short circuit occur, all connected switchboards will experience a blackout. The short circuit protection devices will isolate the fault by opening the appropriate breakers. With correct design of the selectivity coordination in the protection devices, the fault isolation will happen fast and the healthy part of the system will continue to operate properly. Provided overload of the healthy system does not occur, the vessel can hold its position and, depending on design philosophy, and continue to operate until the fault is taken care of. The power producing capacity on modern vessels are usually less than the total power of the installed consumers, e.g. pumps, thrusters, compressors, etc. The reason is that operational profile is used to reduce the generator ratings to again reduce the investment cost. In addition to this, the use of automatic start / stop functionality of power management system to reduce fuel consumption implies that in operation there will not

Be enough power for all consumers to use maximum power simultaneously. Obviously, this introduces the possibility for overload of the generators, which again can give a blackout in the overloaded system.

3. Simulators

In every occupation skilled, trained and experienced people make mistakes, or have errors in judgment. In some of these occupations the results can be disastrous.

Simulators can offer close-to reality training in many important operational and safety related tasks for hazardous environment without any physical risks. For years simulators have been used as tools in system designed and analysis, both in academia and in the industry.
Some may argue that simulator training is not “real world” and therefore operator reactions are not accurately represented. When the systems are running, the background noise starts, the simulator compartment door is closed, the communication starts to flow, the occasional alarm sounds, and the system printer starts to chatter, its as close to real world. At the start of a simulator training course, students are required to produce, check, and have instructor review and evaluate the operational plan & diagram. Toward the end of the course with less instructor coaching required, the plans and diagrams often become less than adequate, and many time even when plans and diagrams are done well, they may not be referred to or followed during the exercise.

3.1. Engine Room Simulator

On the Faculty of Maritime Studies – Split there is Engine Room Simulator (Figure 3.) which electrical power systems and equipment associated with:

- Power generation;
- Propulsion power;
- Power distribution;
- Engine room auxiliaries and “hotel services”.

Figure 3: Engine Control in Simulated vessels – Neptun

3.2. Description

For the full mission simulator, the network mimic is found on the ECR switchboard (Figure 1.). The 6.6 kV breakers and 440 V Main switchboard breakers are controlled from this switchboard while the Emergency switchboard breakers are controlled from the emergency switchboard room. The network configuration during normal operation is 6.6 kV bus-tie breaker closed and 440 V bus-tie breaker open with both distribution transformers in operation, but there are other possible network configurations. Two of the propulsion transformers are cross-connected such that twin motor operation (at reduced power) is still possible even if one of the 6.6 kV SWBD sections is not available. The propulsion motors are then in “half motor” operation. The propulsion motors are equipped with two exciters each, such that one exciter for each motor is in stand-by in case of failure on the exciter or loss of power on one section of the 440V bus.

There are two shore connection supply terminals, one for each 440V section. The shore connection circuit breakers (CB) are operated from the 440V switchboard. It is not possible to connect shore power to any live part of the ship.

The two harmonic filters can be operated from the 440V switchboard. Normally, the harmonic filters are connected/disconnected automatically when "Propulsion On/Off" is selected on one of the engine control panels.

The emergency generators (EG) are manually operated from the emergency generator room. If the emergency generators are set to AUTO, they will start and connect automatically in case of a blackout.

The EMSWBD feeds all the essential equipment for the passengers' and vessel's safety and some DG and propulsion stand-by auxiliaries including the automation system and these will automatically be restarted when the emergency generator(s) are connected.

The emergency switchboard is connected to the 440 V system under normal operation. In a blackout situation, the emergency switchboard will be disconnected from the 440 main switchboard. When the emergency generator(s) has started they will connect to the emergency switchboard and then the selected breaker between the emergency bus and 440 main bus will close. When one of the 440 main switchboards is live, the auxiliaries for the diesels will be restarted.

The following circuit breakers will open at blackout:

- Breakers between 440V switchboard and emergency switchboard
- Distribution transformer breakers 440V side
- Distribution transformer breakers 6.6kV side
- All DG breakers
- Propulsion transformer breakers
- Electrical substation supply breakers

The following circuit breakers reconnect as soon as the first main generator is connected to the 6.6kV bus:

- Distribution transformer No.1 breaker (6.6kV side)
- Distribution transformer No.1 breaker (440V side)
- Distribution transformer No.2 breaker (6.6kV side)
- Distribution transformer No.2 breaker (440V side)
- Electrical substations sequentially

Synchronising the 440V MSWBD-/ EMSWBD bus-tie

Manual synchronising is carried out from the 440V synchronising panel. Generators to be adjusted are selectable from the synchronising panel.

440V main switchboard bus tie

This bus-tie is normally open but in case of failure of one of the HV/LV supply transformers, the 440V bus-tie breaker has to be manually closed.

When the HV/LV supply transformer is available, the primary side of the transformer has to be closed before the secondary side.

The 440V bus-tie breaker will automatically open after 3 seconds.

Partial black-out

If a short circuit or other serious fault on one of the 6.6kV MSWBD sections should occur, the following breakers (connected to the affected section) will open:

- 6.6 kV bus tie breaker
- Generator breakers
- Distribution transformer breakers
- Propulsion transformer breakers

- ➢ Thruster and A/C compressor breakers
- ➢ The Accommodation and galley substation breakers will open, but these consumers can be fed from the other section by a change over switch on the electrical consumer.

The 440V bus-tie breaker has to be closed manually from the 440V switchboard.

4. Test procedures

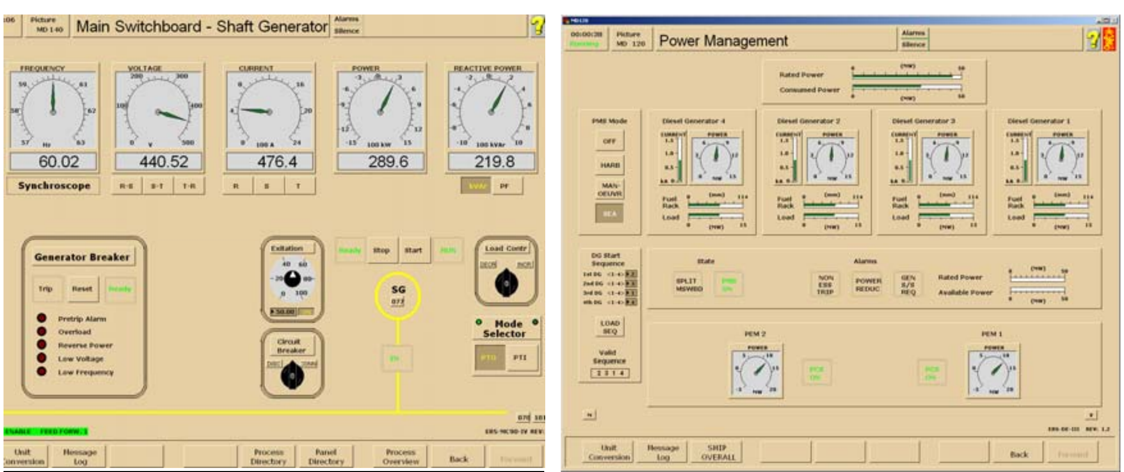
The process of testing students for their competency with the stated diploma includes the following procedures:

1. Written essay examinations which give a detailed look into each individual student's competence and understanding of the covered material.
2. Testing on the part-task trainer which gives an evaluation on each individual student's competence to operate and manipulate the engine simulator. Since the testing covers a set scenario which has been laid out by the instructor/teacher at the beginning of the semester, the student has ample time to practice during the week prior to testing. The simulator software has been programmed to evaluate the student's progress automatically, and a copy of the computer snapshot is saved for later review by the instructor/teacher.
3. Full-mission evaluation in which the students work through a set scenario. instructor/teacher (examiner) preparing a list of faults included in the simulator software and an algorithm for introducing these faults. The faults, their number and respective equipment, are selected in regard to STCW-95 /IMO requirements for the students, his experience and fundamental knowledge. This portion of the evaluation tests the students' abilities to work effectively as a team, utilizing critical thinking principles and personnel management skills; and the ability to prioritize during high stress situations. An evaluation form has been developed so that the instructor has a written evaluation of each lab session which is retained for grading purposes.
4. On completion of the test program the recording stops. Together with the students and using the record, the examiner analyses the watch-keeping safety level and the correctness of the decisions made.

Figure 4 shows one test example which includes:

- Control of power management when the current (load, manoeuvring) increases very fast,
- Take off some consumers,
- System stabilization.

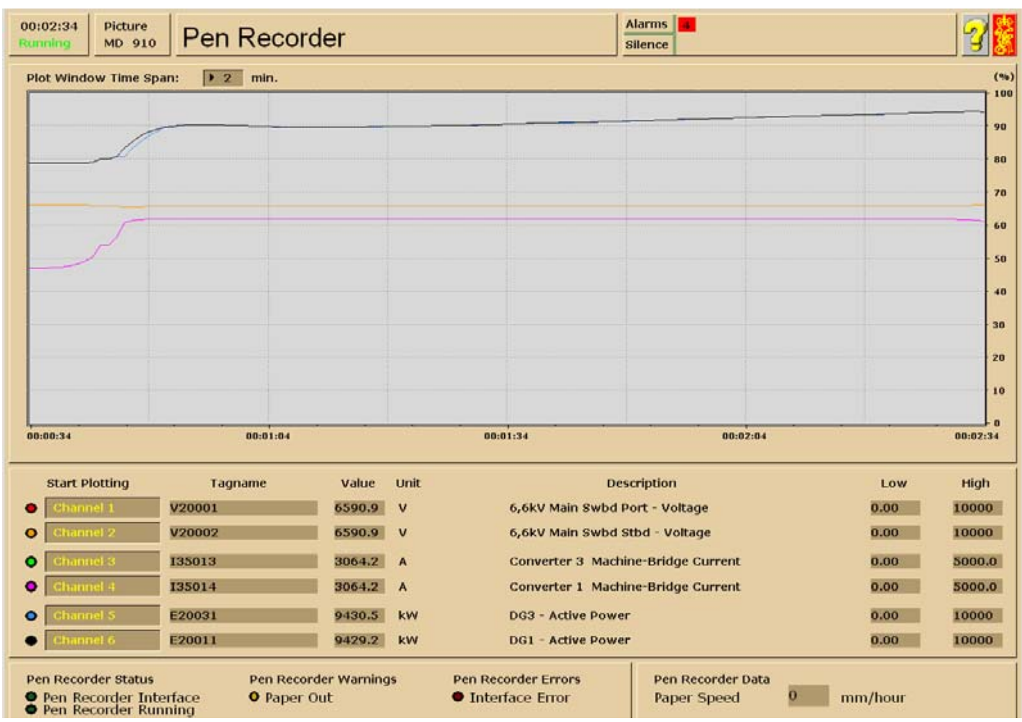
Figure 4: a) Main Switchboard-Shaft Generator; b) Power Management



Specific training objectives include:

- Familiarisation with a diesel electric propulsion plant and the benefits of electric propulsion;
- Enable manual and emergency operation of the entire electrical plant;
- Understand the relationships between overall ship control, power management and propulsion control;
- Understand the need for high voltage (HV) levels in a large power system;
- Identify the role of each principal component in an electric propulsion system;
- Basic operation of static power components, frequency converters and transformers;
- Understand the need for system earthing/safety procedures during routine and emergency conditions;
- Understand the general protection requirements for electrical power equipment;
- Understand the demand for generated electric power to be shared between ship propulsion and accommodations;
- Understand the role of an overall Power Management System (PMS). Locate/operate main and emergency propulsion control points within the ship.

Figure 5: Example of a training diagram report



5. Conclusion

The purpose of simulation work is to develop a model on simulator for study the dynamic behaviour of the ship electrical system, engine room or ship bridge. During the simulation we do some mistakes but we can learn from mistakes especially our own and share with others (during workshop or during the training). Training of students/ship crews can do reliability for certain situation using ship or ship bridge/engine room simulators. The lectures have developed training scenarios with particular attention to human factors.

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Biography

Maja Krčum is a graduate of the Faculty of Electrical, Mechanical Engineering and Naval Architecture, University of Split. She holds an MSc from the Faculty of Electrical Engineering, University of Zagreb. She was the Head of Department of Marine Power Engineering and Electronics in Split and Šibenik and is currently quality manager at Faculty of Maritime Studies Split. She has been participated in a number of both national and international conferences where her papers and presentation were generally acknowledged as an active and valuable contribution towards the development of her profession. She is the author of books, journal and many conference papers. Her primary interest lies in the field of shipboard propulsion systems, with a special emphasis on electrical propulsion and its numerous applications (simulation methods). She is also a member of several national and international societies for example: the Institute of Electrical and Electronics Engineers (IEEE), Croatian Society for Communications, Computing, Electronics, Measurement and Control (KOREMA); the International Emergency Management, Society (TIEMS…). Maja has taken part in two research project and she was member of Tempus Cards SCM 2006 (Project Quality assurance in University Teaching).

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. 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". Now, she is a senior lecture at the Maritime Faculty University of Split. Her research interests include database design, genetic algorithms, 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…)

Zdeslav Jurić was born in Slit, Croatia (1974). He was graduated from the Faculty of Maritime Studies -Split, University of Split (2002.). He worked as junior researcher at the Faculty of Maritime Studies –Split. His primary research interest lies in the field of mechanical and propulsion engineering and also in some system for education students.