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Safety aspects within dieselelectric propulsion

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Safety aspects within Diesel Electric Propulsion

Diesel Electric Propulsion is today a quite common type of propulsion system.
In former times it was mainly used for ships with special functions like:

- Icebreaker
- Research vessels
- Cable and pipe layers
- Frigates, Submarines
- Drilling, crane and all other kind of rigs
- Supply vessels
- Cruise ships
- Ferries

Nowadays also:

- Naval ships
- Ro Ro Ferries
- Shuttle tankers
- Product tankers
- Fishing boats

are equipped with diesel electric propulsion systems. In the future we expect a growing market for diesel-electric propulsion systems.
If international regulations request two independent drive systems for ships which are carrying dangerous goods the market for diesel electric propulsion will rise .
This paper will not focus on the advantages of the diesel electric system. The principle aspect will be safety.

What do we want to reach with more safety?

- We want to avoid damages of the component
- We want to reach a high personal safety for the operating personnel
- We want to avoid damages /losses of cargo
- We want to avoid the loss of the ship
- We want to avoid situations which can cause ambient pollution

Conclusion:

- We want to avoid accidents!

How we can reach these goals?
Which aspects fulfil these requirements and reduce the rise of an accident?

We think we can fulfil the requirements if we take care about three mayor points:

1. Safe component design
2. Safe system configuration
3. Taking care of the „human factor“

I will start my explanations with Point 1.
Safe component design
First of all the components of a diesel electric propulsion system are as following:

- Diesel motor or gasturbine
- Generator
- Switchboard with breakers
- Transformers / Reactors
- Converters
- Propulsion motors
- Gearboxes, thrust bearings, shaft line and propeller
- Control, alarm & monitoring system
- Auxiliary and auxiliary supply system

If we are talking about component safety I will of course talk about the components, which belong to the normal scope of an electrical supplier.

Component generator

Mostly the system voltage of a diesel electric driven ship is 3,3 up to 10 kV.
This means medium voltage. This is caused by a high electrical power demand of these systems.
High generator power means high short circuit apparent power. At low voltage this power will cause short circuit currents which will exceed the maximum permissible ratings of the available low voltage breakers. On the other hand this high power will lead to a high number of parallel connected cables would be an economic disadvantage .
To reduce the short circuit current in the system it is of course possible to reduce the subtransient reactance XD" of the generators. This however, will lead to higher harmonic distortions in the network voltage caused by the converters.
If we are considering the safety aspect of the component generator we have to see a medium voltage generator.

<u>Mechanical:</u>

- shaft strength for short circuit torque
- Bearing design
- High degree of protection
- Double tube water cooler

<u>Electrical:</u>

- Harmonic additional losses (heating)
- Insulation in VPI technology
- Micalastic
  - Impregnation with synthetic epoxy resin in a vacuum vessel and hardening in a drying oven.
  - High dielectric strength
  - High thermal conductance
  - High resistance to periodic thermal expansion
  - Insensitivity to moisture, oil and chemically aggressive atmospheres
  - Resistance to tropical climates
  - Long life and high service reliability

Component mediums voltage switchboard with breakers

The purpose of the switchboard is to distribute the power coming through the generator breakers through outgoing breakers or contactors to the consumers. In case of failure the switchboard has to clear a short circuit by opening the breaker or contactor. That means the switchboard has to be designed to carry the maximum transit short circuit. The breakers and contactors have to be capable to interrupt the subtansient short circuit current. A busbar short circuit inside the switchboard can have dramatical consequences. To fulfil the requirements we can provide two different switchboard designs.

1. The air insulated switchboard with vacuum breaker and contactors 8BK 20/30.

8BK 20/30

The special features regarding personnel safety are:

- Arc fault tested metal enclosure (IEC 298)
- All switching operations with door closed
- Verification of safe insulation from supply with door closed
- Earthed metal partitions and shutters prevent contact with live parts.

Regarding reliability

- All interlocks are mechanical with key-operated access shutters to prevent faulty switching.
- High degree of protection against ingress of foreign particles, under all operating conditions
- Insulators with high resistance to pollution
- Guaranteed electric strength without conductor insulation.

The second possible design of the medium voltage switchboard is the SF6 insulated switchboard 8DA 10 with vacuum breakers.

8DA10

The special features regarding safety are:

- SF6 insulation of high dielectric quality
- Single pole enclosure from cable to busbar
- Single pole enclosure
  - Phase segregation excludes phase to phase faults and ensures the maximum dielectric stress is only phase to earth
  - torodial-core current transformers installed outside enclosure, free from dielectric stress
  -

Operator safety

- Closed pressure system
- Whole switchgear is completely shock-proved
- Capacitive voltage indication for dead or alive state by capacitive indicators
- Operating mechanism and transformer secondary components accessible outside enclosure
- Complete switchgear interlocking with interrogation interlocks.

Operational reliability

- Closed pressure system ensures protection against environmental influences
- Single pole enclosure excludes phase-to-phase faults
- Maintenance-free primary section inside enclosure
- Localisation of faults by division into compartments

SF6- insulation

- Self restoring
- Renewable
- Can be checked for quality
- High degree of protection against environmental influences

Characteristics of SF6

- Non-poisonous, non-flammable, inert
- Self restoring insulation
- Arcs of low current are self extinguishing
- Minimal environmental effect
  - Gas leakage rate < 1% annually
  - Renewal of gas in a closed system
- SF6 only insulating, not arc-extinguishing medium therefore no arcing products
- No oxidation inside enclosure.

After the loss of SF6 in the section the switchboard remains operational.
The switchgear is divided into different compartments:

- Busbar
- One gas compartment per feeder including the cable terminators
- Circuit breaker
- One gas compartment per feeder including the cable terminators
- Gas tight barriers between busbar and circuit breaker compartment
- The three-position selector is located in the busbar compartment
- Safe replacement of circuit breaker chamber with live busbar possible
- Practical division of gas compartments allows easy localisation of faults.

Component transformer or reactors

The purpose of the transformers is to reduce the generator voltage to a feasible network voltage to supply the ship service network or to transform the voltage level adequate to the chosen converter input voltage.
On the other hand short circuit currents will be brought to lower values via the transformer and the effects of harmonic distortions created by the converter can be reduced. The transformer has to be capable to withstand a short circuit.
In contrast to the supply transformer, it is necessary duty to pay attention to the influences of harmonics caused by the converter when providing the design for converter operation. Possible d.c. premagnetication and load unbalance in the event of faults have to been taken into consideration. Ignoring these converter specific influences can cause thermal or mechanical damage to the core and windings of the transformer and possible breakdown of the propulsion system, or at least a considerable reduction in service life of the transformer.

The Geafol Transformers perfectly meat these requirements. The Geafol Transformer is an cast-resin dry-type transformer.
The low voltage winding is a strip winding comprising of viewed radial - thin, but-viewed axially very wide strip conductors.
Special insulation materials, with a glass cloth of micabase, impregnated with high temperature-resistant esterimide or epoxy resin, are used as layer insulation.
As a result of thermal treatment, the conductor and insulating materials are bounded together to form a compact, solid tube winding which can fully withstand the short circuit forces.
Because of the large number of turns, the high voltage winding is divided into individual section coils formed from aluminium conductor strips.
High quality insulating materials in the form of plastic film (polyester) or aramide paper with excellent dielectric and thermal properties are used as layer insulation.
As a result of casting under vacuum with powdered -quark- filled epoxy resin, the HV winding also forms, after the temperature and time-controlled curing process, a compact solid tube winding.
Between the individual tens of strip windings, there is only relatively low voltage per turn of the transformer. This leads to low dielectric stressing of the insulation and freedom from partial discharges up to approximately double of the rated voltage.
The Geafol converter transformer handles the electrical stress resulting from the commutation processes by means of layer insulation which is reinforced compared with the standard design.
The insulating materials used in Geafol transformers are flame-resistant and self extinguishing since they contain a high proportion of non-inflammable inorganic substances. The non critical behaviour of a Geafol transformer has been proved in fire tests.

Component Converter

The purpose of the converter is to convert the fixed supply voltage into a stepless controlled voltage and frequency to supply the propulsion motor.
The converter has to be designed in that way, that

- An internal short circuit, due to a faulty semiconductor
- An external short circuit, due to a failure at the motor or transformer
- A shot through, due to a failure in the converter control system.

do not lead to a unacceptable conditions for the converter.
To reach these requirements cyclo, synchro and PWM converters can either be equipped with fuses to protect the semiconductor against short circuit or can be designed as fuseless, short circuit proven converter.
In case of protection of the converter fuses are used. These fuses are special fast acting semiconductor fuses.

The selection of the fuses has to be done very carefully to reach the optimum of protection in the entire system. The problem that the short circuit current is very low if one generator is running, has to be taken into account during the design stage. It has to be ensured that also under this conditions the fuses are also acting probably.
Fuseless converters have to be short circuit proved. This means, the converter has to be able to carry the maximum short circuit current until superior protection devices react.
In case of a ship network, the circuit breaker in the main switchboard has to open. The power conductor of a short circuit proven converter has to be designed such as that under normal conditions sufficient thermal reserve is available so that they can withstand the thermal demand during short circuit conditions.
To increase the personnel safety, for example, the medium voltage converter SIMAR DRIVE ML is equipped with a new optical link between the control system and the power section. Already today firing pulses in high voltage applications for thyristors are transferred from the control system to the power section via optical cables. The optical link between the SIMAR DRIVE ML to the full digital propulsion control system SIMADYN D has been innovated. The connection between power section and control system consists of 2 optical cables. Through this cables all necessary information for the firing pulse calculation are transferred serial. All actual values like current and voltage as well as all status information for monitoring of the converter are transferred via the same optical cables. The advantage of this opto-electronical link is the optimal galvanic separation between high voltage system of the power section of the converter and low voltage system of the propulsion control system. Highest personnel safety is generated.
With this technique an optimum of electro magnetic compability (EMC) will be achieved as well.

Component Propulsion Motor

The propulsion motor fed by the converter with variable voltage and frequency drives the propeller directly or via a gearbox.
They are designed as

- Induction motors or
- Synchronous motors

Synchronous motors are designed with cylindrical rotors for high speed or salient pole machines for low speed.

In the design of converter fed motors special criteria must be considered in the electrical dimensioning.
Of course:

- Nominal voltage
- Number of poles
- Losses
- Commutating reactance
- Motor power factor
- Overload capacity

have to be adjusted to the converter.
In addition effects of harmonics in the stator current which leads to

- Additional losses
- Oscillating torques
- Effects of variable speed operation

on motor dimension has to be considered.

The variable - speed capability requires suitable ventilation and excitation.
Normally the propulsion motors are equipped with at least2 separately driven fans and an air to water heat exchanger. The heat exchanger is designed as double tube cooler to prevent the possibility of entering cooling water due to a cooler failure into the motor.
The cooling system of the motor is designed to operate with reduced power if one fan fails.
The possibility of cooling the motor with ambient air in case the cooling water system fails, can be also provided.
In some cases, high speed propulsion motors can be equipped with shaft mounted fans, if it is ensured that also at low speed a sufficient cooling of the motor is ensured.
The excitation system of converter fed synchronous motors has to be designed, that it provides sufficient excitation power at low speed, during acceleration and reversing.
Additionally the design has to meet the following criteria as in case of the generator:

- Shaft strength for short circuit torque
- Bearing design
- High degree of protection (IP56 up to lower side of shaft)

Also at the propulsion motors we are using the Micalastic insulation with the features:
Impregnation with synthetic epoxy resin in a vacuum vessel and hardening in a drying oven.

- High dielectric strength
- High thermal conductance
- High resistance to periodic thermal expansion
- Insensitivity to moisture, oil and chemically aggressive atmospheres
- Resistance to tropical climates
- Long life and high service reliability.

To put it into a nutshell: Much can be done for safe component design.
All these items explain what leads to a reduced possibility of failures, and to a reduction of the effects on the equipment during a failure.

Safe system design

As important as the safe component design is a safe system design. The system design has to ensure that all components of a drive system are working together.
The system layout has to evaluate the right nominal ratings of each component under nominal conditions and of course under irregular conditions.
During the design stage

- short circuit calculation/simulation
- harmonic distortion analysis and
- torsional vibration analysis

have to be performed.
The short circuit calculation leads to a proper design of switchboard and breakers. It has to be ensured that their ratings are sufficient to carry and to operate short circuit currents.
But also the electro magnetic forces, caused by the short circuit currents, have to be considered in the design of cable connections and cable mounting on the cable trays.
With the harmonic distortion analysis we check if, the harmonic distortion is kept to limits, which ensures that no other equipment on board leads to mal function due to the harmonics. The limitations are given by the regulation of the classification societies or other authorities.
The harmonic analysis is performed with computer simulation tools. We, for example, are using the computer program KOPL.

With this tool we are simulating the whole ship network from generator to propeller motor on a mathematical base. With this real time program we can perform a simulation of various operation conditions.
Mainly it calculates the harmonic distortions at various network points. But also short circuit currents and short circuit torques can be simulated. A check of the right component sizing will be done before they are finally designed and manufactured.
As important as short circuit calculation and harmonic distortion analysis is the torsional vibration analysis. It has to be checked at which operational speed points vibration resonance effects have to be expected. If the resonance points are determined, a continuous operation at this speed has to be made to avoid unacceptable mechanical stresses at the effected components.
A proper design of all protection, safety and monitoring systems also belongs to a safe system design. The protection system of the power-generation and distribution has to include

- Short circuit protection
- Differential protection
- Earth fault protection and isolation monitoring
- Over current protection
- Over- and under voltage protection
- Over- and under frequency protection

Besides standard functions the power management system has to include:

- Synchronising
- Regular load sharing
- Automatic restart of generator sets after black-out

The functions

- Power limitation of the drive system according to the available power
- Past power reduction of the drive system if a generator set suddenly fails.
- Acceleration and deceleration of the drive system according to the capability of the generator sets.

The protection system of the converter- motor system has to include the functions

- Monitoring of the fuse and/or semiconductor status. A failure of them has to lead to an immediate stop of firing pulse distribution.
- Check of motor current and voltage according to the speed of the motor
- Overspeed protection of the motor
- Limitation of maximum propulsion power, if the monitored conditions of the associated components are reaching a defined status.
- A shut-down of the propulsion system, if monitored conditions of a component shows an unacceptable status.

All these points which will lead to a safe system design don't have the effect that we get rid of component failures.
According to the statistics and to Murphy's Law „Every thing what can happen will happen."
We have to reduce the effects of component failure in providing redundancy. Already today the rules are requesting redundancy. In addition the classification had introduced an additional notation regarding redundancy of diesel electric propulsion.
The system requirements of this notation include:

- Prime mover
- Main switchboard
- Converter
- Propulsion motors
- Control and Monitoring systems
- Auxiliary system

To fulfil the requirements the Main Switchboard has to be divided in two different sections with automatic acting tie breakers.
Converters and auxiliaries have to be separated in the same manner. This includes also control and monitoring.
Finally the request of the classification society with notation „Redundant Propulsion" is as following:

„After a single failure in an electrical or mechanical component sufficient propulsion power for manovering and transit of the ship under bad weather conditions is available."

Which redundant systems are possible shows for example the propulsion system of the double ended ferry type Jumbo Mark II for Washington State Ferries, Seattle. Here each end of the ferry is equipped with a double motor. Each motor is supplied by a redundant cyclo converter. One thyristor bridge per phase is always active and the second is in stand-by.

If a failure occurs the system changes over automatically from one bridge to the second bridge within a few seconds. The complete propulsion control system is built up redundantly. Also here one system is active and the second is in stand-by.

Also here a change over from one to the other system takes place within a few seconds.

The human factor

One main safety aspect of the diesel electric propulsion system is safe operation.

To verify this item we got a statistic of the German „Bundes Lu^ft^fahrtamt".

We believe in the field of air traffic accidents that every accident is investigated deeply to find out the reasons. For the years 1983 - 1992 the statistic shows the following causal factor which had led to Jet operational total losses:

74%	Human factors
18%	Technical factors
8%	Environmental factors

Also for ship operation statistics are existing.

Between October 1986 and March 1991 the four German „Seeämter" had to investigate 322 accidents. The following reasons has been investigated:

6,2%	technical reasons
2,8%	cargo reasons
1,2%	weather reasons
1,0%	tug boat operation
0,9%	no knowledge of water depth
4,1%	no reason have been investigated
84%	human error

What are the reasons for this high figures of accidents caused by human errors?

We believe

- Unqualified Operational personal
- Unqualified education of the personnel
- Structure of operational personnel for example communication problems
- Overload through complex and partly not useful technique
- Overload through very small number of operational personnel

What can we do to improve the situation for the operating personnel?

We have to provide

- Good, complete documentation
- Maintenance and repair instructions
- Training
- Service facilities

Documentation

The documentation has to be delivered completely. It has to be understand able.

Today's documentation of a diesel-electric propulsion system consist of various binders.

The documentation has to be structured that it is possible to find the requested papers in short time.

We have to provide guidance how to get to the requested item.

Next to electrical diagrams and program listings a description about the possible operation modes and performance has to beadded.

Irregular conditions including warming and alarms and the necessary and possible reactions have to be included.

Maintenance and repair instructions

After verifing the problem, the personnel has to be able to repair the component. For this purpose repair instructions have to be available. Required tools and spares have to be on board and the personnel has to be able to handle them. Maintenance procedure have to be clearly descripbed to ensure that the systems are kept in good conditions.

Training

To understand the documentation, to operate the system within the normal operation modes and to use all possible performance, the operating personnel has to be trained. This should include a theoretical part as well as a practical part.

Service facilities

We as a supplier of these systems have to provide service facilities which makes fast assistance possible.
This has to include possibilities to look through Satcom connections on-line into the systems to help to localize the possible errors and to give instructions to solve the problems.

Conclusion:

To reach a safe system the following points have to be fulfilled

- Good design
- Quality equipment
- Quality workmanship
- Adequate commissioning and testing
- Qualified operation
- Qualified management, both on board and ashore

Good design is more than the selection of high-quality component.
Due to the fact that a never-failing component does not exist, a redundancy is necessary.With components which are not redundant it has to be ensured that the operator is warned about its failure, and that the failure is leading toward a safe operational mode rather than an unsafe. High reliable equipment will reduce the number of failures, but will not reduce the effects of failures when they occur.
Safety by redundancy has a different nature. The primary object is not to avoid failures. The purpose is to be able to keep safe operation even when failures do occur.
The vessel is still safe, although at a lower performance level.
Good design and redundancy are design matters.
Operational safety is the matter how these systems are used in practice. Vessels which are built with redundant and flexible solutions have to be used and to be understood by the operators.
In general the systems have to be adapted to the operation circumstances. Operational safety requires understanding of the system.

The operator has to be able for example to interpret warnings and alarms presented by the system.
The operator has to select the optimum correcting action to specific events.
Finally I would like to point out that discussions with shipyards and owners normally end up with discussion of kg fuel per kW and DM investment per kW. and not about increased safety onboard. Maybe it is because there is no dimension to measure safety.