PROTECTION PLAN AND SAFETY ISSUES IN THE SHORE CONNECTION APPLICATIONS

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ABSTRACT

Shore connection technology bring an interesting solution avoiding ships to run their auxiliary engines at berth by providing electrical power directly from onshore electrical distribution system. Shore connection design faces technical issues regarding equipment protection and safety. This paper presents first the shore connection solution architecture and sum up the technical issues regarding the coupling of ship power system to shore installation, the protection system design with low short-circuit current and the safety risk mitigation during the connection and disconnection phases.

INTRODUCTION

When ships are at berth, they use their auxiliary engines and/or generators to power onboard systems and equipments, generating substantial pollution in port areas and consequently serious health issues. International regulation and dedicated associations like IMO (International Maritime Organisation) strongly require the vessels to reduce deeply their pollution when at berth. In this context shore connection technology bring an interesting solution avoiding ships to run their auxiliary engines at berth by providing electrical power directly from onshore electrical distribution system.

I. SHORE CONNECTION TECHNOLOGY

Shore connection system shall be suitable for all ships type and size, from the medium size cargos and container ships up to the biggest cruise ships. The electrical power needed by these kinds of ships can vary from 1MVA to 20 MVA. The electrical energy shall be supplied to ships in both frequency 50Hz and/or 60Hz (e.g. 70% of the ships are designed for 60Hz while only 30% port's electrical power supply is in 60Hz) and for two standardized voltage: 6.6 kV and 11kV according to IEC/IEEE/ISO 80005-1 standard [1] [3]. The ships need high availability power supply, with smooth transition between the onboard sources and onshore power, without impact on the port electrical distribution system.

The diagram shown in fig.1 illustrates a generic architecture for a HV shore connection system, with frequency conversion feature.

The Shore Connection System Architecture can consist of:

- a MV switchboard supplied by MV incomer from the port power system,
- a MV/LV step down transformer,
- low voltage Grid Frequency Converters (GFC)
- a LV/MV step up transformer to connect the GFC to the ship MV distribution system,
- a output MV switchboard who supply the ship,
- a cable reel, plugs and sockets adapted to each ships type.

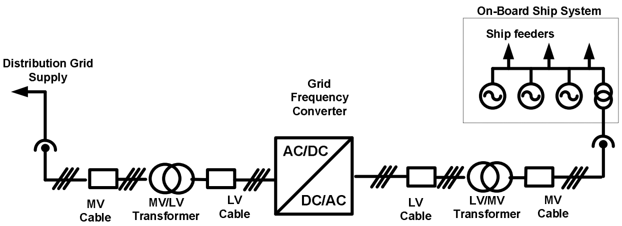

Fig.1: The Shore Connection Distribution Grid Architecture

Shore connection technology has to meet several constraints to be attractive:

- cost effective solution,
- quick installation to limit its impact on port activities,
- ensure safety during cable connection and disconnection,
- ensure reliable and available shore connection operations.

Schneider Electric has developed the ShoreBoX™ concept to propose a cost effective solution with high performances. As shown in figure n°2, the Compact ShoreBoX™ concept deals with a complete solution including electrical power equipment, control system, safety system and heating and ventilation of each substation compartments.

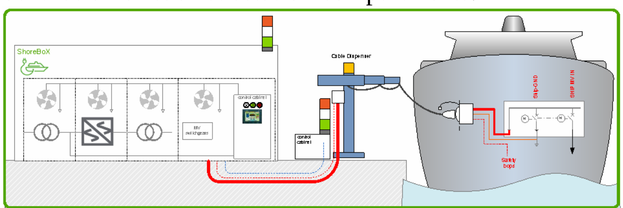

Fig.2: CompactShoreBoX™ Solution

The main key points are mentioned hereafter in table n°1.

Durability
o Durability of MV switchgears to handle the expected number of connection / disconnection operation,
o As shore connection substation is installed on berths with severe environment conditions, the design of the solution and selection of electrical equipment takes into account temperature, rain, humidity, dust, wind, presence of salt, snow, ice, shocks,
o Filters and suitable painting and coating for salt environment and chemically substances,
o Temperature & humidity conditions,
o Degree of protection according IEC 60529;

Energy savings and voltage quality
o The GFCs technology offers high energy efficiency, guarantee ship voltage quality and very good level of upstream harmonics thanks to power factor correction embedded;
Protection system
o Transformers fault detection,
o Coordination with ship protections;
Reliability and availability
o Proper selection of the equipments,
o Proper design and integration of the solution,
o Reliability and availability improvement by using modular GFC, adequate redundancies and spare parts services;
Safety
o Safety system based on pilot wires to automatically lock out MV switchgears before connection and disconnection;

Tab. 1 : ShoreBoX™ key points

The connection of a ship power system to the grid induces some technical challenges. Some of the main technical issues are detailed here bellow.

II. SHORE CONNECTION OPERATION

The connection of a ship power system is performed without any blackout by synchronization and parallel operation of shore substation with ship generator. Ship generators are disconnected when the entire load is supplied by the shore substation.

The output voltage of shore substation is controlled by the GFC. The GFC has very low voltage and frequency droop slopes low compared to ship generators (fig.3).

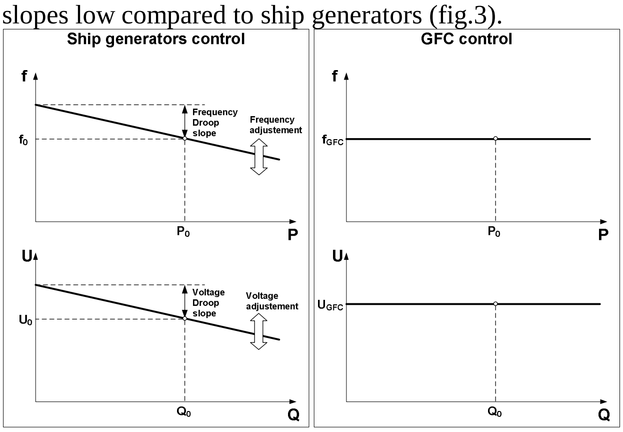

Fig.3: Frequency and voltage control

The synchronization is performed manually or automatically as following:

- voltage magnitude is set by adjusting the alternator current excitation,
- frequency and phase are set by adjusting the motor intake valve.

When the voltage is synchronized, the ship generators are coupling to shore substation. The error between shore and ship voltages magnitudes, phase and frequency induces transient phenomena and also power flow between ship generators and shore frequency converters as shown in fig.4.

During the parallel operation, depending on the ship generator synchronization errors, the GFCs need to be able to handle a reverse power flow as shown in figure n°4 :

- if the ship voltage magnitude is higher than shore voltage, a reactive power Q will flow into the GFCs,
- if the ship voltage phase shift is positive, an active power P will flow into the GFCs,
- if the ship frequency is higher than the GFCs, an power will flow into the GFCs.

This phenomena needs to be assessed to verify that no GFC protection trip will happen and that the system is stable.

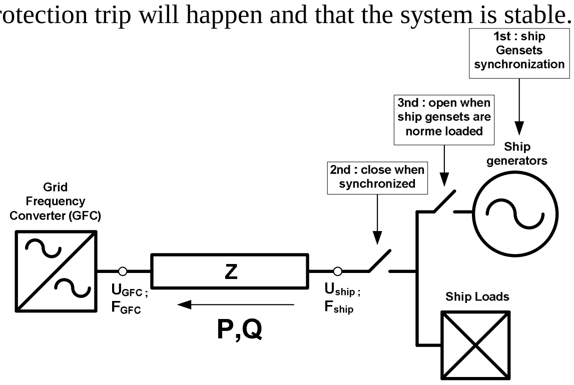

Fig.4: Electrical diagram of parallel operation of GFC and ship generator.

III. PROTECTION SYSTEM

Coordination with on-board loads protections

The IEC 80005-1 [1] requires that shore substation needs to provide enough short circuit current to trip the protection relay of the biggest load on the ship, in the case of short circuit on the ship side.

A particular attention has to be paid to ANSI 50/51 and 50/51N protections coordination requirement, considering limited level of short circuit currents provided by static frequency converters and that shore protection system need to be set according to each ship.

Output transformer protection

Dedicated attentions have to be paid for shore system internal faults. Transformer internal faults such as inter turns faults may be difficult to detect due to the low level of the corresponding line current. On the other hand, with frequency power conversion we need to take in account the limited value of the short circuit current with its possible collapse within 1s.

Consequently, for transformers the use of two winding differential relay (ANSI 87T protection) and restrained earth fault protection (ANSI 64REF) would bring a reliable solution for any kind of faults. To secure the system, additional protections and thermal overload (ANSI 49T) should be installed.

Protection of paralleling operation

During shore start sequence, there is a risk that shore substation closes its main output breaker while ship has

already energized the connection cable. To prevent shore to be connected without synchronization to a ship, dead bus verification (ANSI 84) is set on the main output breaker. This protection enables the closing of the main output breaker only if no voltage is detected downstream.
During parallel operation of shore substation with ship generators, a reverse power protection (ANSI 32) is set on the main output breaker of shore substation to prevent the ship to provide power on the grid or to supply a fault on shore side. Moreover, to guarantee acceptable voltage tolerance to ship loads, under/over voltage protection (ANSI 27 and 59) and under/over frequency protection (ANSI 81 U/O) are also set on main shore output breaker.

Connection cable continuity monitoring

In the case of breakdown or high impedance (poor contact) of the ground conductor, the bonding potential between shore and ship could exceed 50V during ground fault and be dangerous for operators (fig.5). As the shore-to-ship cable is handled many times, for each ship connection, this risk is not minor. Hence, a ground check system is installed between shore and ship to detect the ground conductor failure. The principle is shown in fig.6; a current is injected in an additional pilot wire and passes through the ground conductor; if a failure occurs on the ground conductor, the ground check system will trip the main circuit breakers on both side.
There is also the potential risk of a power connector resistance deviation (due to poor contact) that could result in plug arcing phenomena. To bring a correct detection of that kind of failure, negative sequence overcurrent protection (46) is set on shore main output relay.

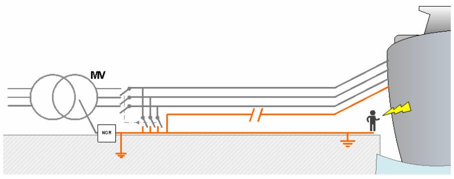

Fig.5: Ground conductor failure

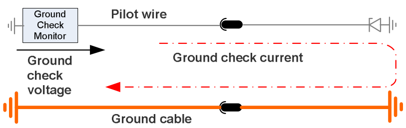

Fig.6: Ground check system

IV. SAFETY SYSTEM

Handling, connection and disconnection of MV plug induces electrical hazards. As shown in figure 7, when performing an connection/disconnection, the operator has an access to power connectors and then can experience a shock hazard if the power connectors are not disconnected and not earthed. The possible risks are summed up hereafter:
- fail to disconnect from shore substation,
- fail to disconnect from ship power system,
- fail to discharge the MV cable [2].

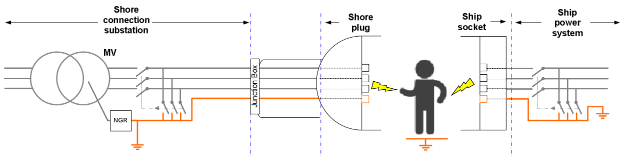

Fig.7: Electrical hazards during connection/disconnection

The main shore connection safety functions are specified as following:
- Safety function F1: disconnection of MV plug and socket from the sources,
- Safety function F2: discharge of MV cable,
- Safety function F3: prevent access to MV socket and plug while not grounded.

IEC/ISO/IEE 80005-1 defines specific measures to prevent these risks. The recommended measures are classified as follow in the standard:
- emergency shut down,
- conditions for shore connection start sequence (conditions on main breaker closing and earthing switches opening),
- conditions for plug handling during plugging and unplugging (opening disconnector and closing earthing switch on both side).

Generally, shore operation will be performed by non qualified electricians teams. Consequently all the elementary operations shall be simple and secured. That is why the safety during shore connection and disconnection is achieved by the integration of two basic concepts:
- operating instructions and procedures,
- automatic interlocks managed by a safety system (see figure n°8).

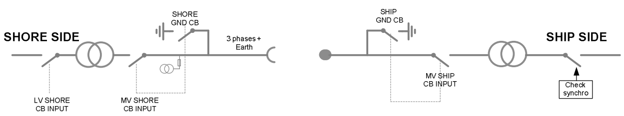

Fig.8: MV shore to ship connection architecture

The aim of automatic interlocks is to prevent all the risks intrinsic to the MV plug handling, during plugging and unplugging phases. Here after are mentioned, the main actions to guarantee safety:
- during MV plug handling:
  - o permit the plug handling when shore circuit breaker is locked opened and to maintained earthing switch closed,
  - o prevent to handle MV plug if not earthed,
- during MV plug plugging
  - o prevent the access to MV socket if not earthed,
- during MV plug unplugging before power connectors disconnection :
  - o open the circuit breaker and the disconnector automatically on both side,

- o close the ground switch automatically on both side.

V. STUDY CASE

The study case presented here is composed of a 3MVA shore substation supplying a 3MVA ferry boat at 11 kV. The diagram presented in fig.9 show the general electrical architecture.

Synchrocoupling simulation

The sequence of coupling of ship to shore coupling has been simulated using a transient Matlab Simulink model of the global power system representing :

- the power electronics control of the GFCs,
- the speed and voltage control of ship diesel engines,
- the frequency droop control of alternators.

The coupling sequence is simulated with a 10° phase shift and 5% voltage errors between shore and ship voltage. As shown in fig.10, the transient active power between shore and ship absorbed by the GFCs reached about 1MW peak, but the GFC protection is not tripped and the system remains stable. However a particular attention has to be paid to the direction of the phase shift and voltage difference to prevent ship gensets to not reach their P,Q limits.

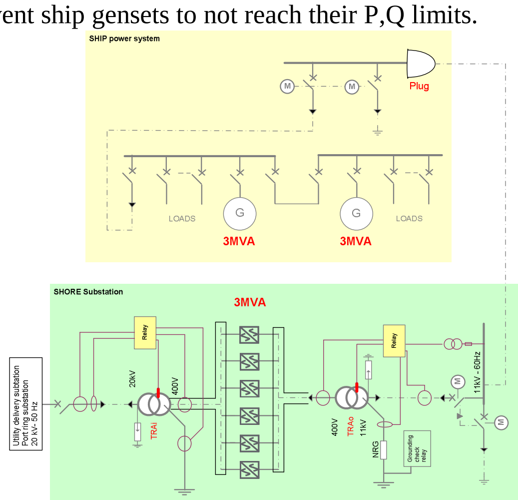

Fig.9: study case architecture

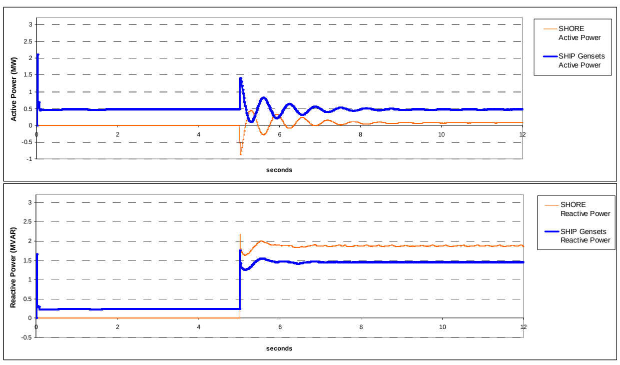

Fig.10: simulation of shore to ship synchro coupling sequence

Safety system design principles

Safety system (fig.11) is ensured by pilot wires which are a part of the power cable. During plug disconnection, the plug design permits to first disconnected the pilot contacts to shutdown and secure the installation before the power connectors disconnection.

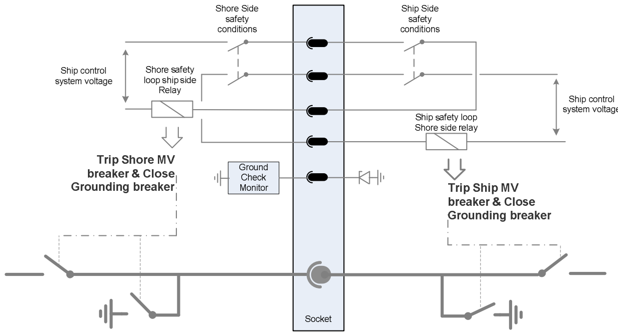

Fig.11: safety loops diagram

Loops and relays

- a safety loop for shore connection substation and 1 safety loop for ship switchboard,
- a safety loop is basically composed of a DC power supply and a relay,
- when the relay is no longer supplied, its auxiliary contacts disconnect the MV cable (by opening the main breaker) and ground the MV cable (closing ground switch).

Emergency stops

- e-stops on shore and ship side trip the 2 safety loops.

VI. CONCLUSIONS

Air pollution and regulations are forcing the whole maritime industry to look for greener technologies. The present work outlines some technical specificities of a new application concerning the ship connection to shore electrical distribution systems and some best practices are introduced. A new shore connection solution is presented, CompactShoreBoX^{TM}, who provide a cost effective offer, with high efficiency, capable to reach important powers by paralleling, fitting different ships needs and specificities. This belongs to a TVD (Tested, Validated, and Documented) solution provided by Schneider Electric.

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