Transient Analyses of a Shore-to-Ship Connection System

M. Ion, M. Megdiche, S. Bacha, D. Radu

Abstract**-- The pollution level in the area of the major maritime ports is increasing at an alarming rate. The advisable solution to decrease the ship's emission volume is to shut off its onboard diesel generators and supply the onboard electrical system from a shore grid. This paper analyses a new Shore-to-Ship Connection System solution. The main advantage of this solution is the ability to perform frequency conversion, using a Grid Frequency Converter. In order to study the possible events that can occur during the shore-to-ship connection, we first build the simulated system model. Knowing that the ship has a large onboard system, a strategy for aggregation loads is applied. Finally, a transient behavior analysis of the port's grid supplying the ship system is performed.**

Keywords**: Ship, Shore-to-Ship Connection, Grid Connection Converter, Transient Analyses.**

I. Introduction

An alternative power supply system for ships during the berthed period is being developed in many ports around the world [1]. While docked in port, the maritime ships shut off their propulsion engines and auxiliary diesel generators. When no diesel engine is used, the emissions and noise levels are dramatically reduced. When the ship is connected to the harbor power supply system [2], the shore power supply must manage conditions imposed by the onboard electrical system and it must be able to substitute the ship's internal generators. Ship electrical load at berth can consist of lighting, chillers, pumps, fans, elevators and so on. The correct sizing of the shore system is the key to a reliable and workable system and it must be calculated according to the nature of the ship load when berthed.

Depending on the size of vessel, the onboard power level can vary from 1 MVA to 20 MVA. The onboard distribution system is similar to a small scale industrial grid where the motors can represent almost 2/3 of total loads and require an adequate response from the supply system [4]. It is known that the ship's on-board system uses multiple generators for redundancy and efficiency.

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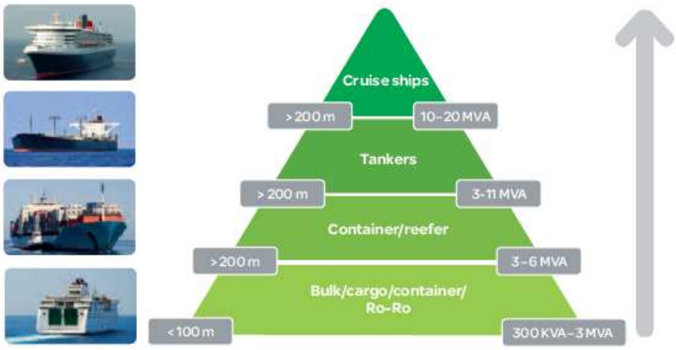


Fig. 1. Variety of vessels at berth [2]

. The generators are designed for large loads causing oscillations, distortion and major transient power demands.

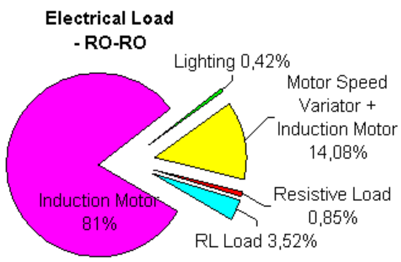


Fig. 2. RO-RO (Roll-on/roll-off ship – used to carry wheeled cargo) Load Breakdown

As the load breakdown shows, the induction motors have a major influence on the ship system. The starting conditions of the inductor motors, the transitory periods and the faults that could appear in the ship system must be studied in order to evaluate the relative capacity of the shore power supply. To perform these assessments, the shore connection system has to be modeled considering its grid frequency converters and particularly its fault current limitation. As the statistics show, European ports run a 50 Hz electrical grid, while approximately 70% of vessels have an internal system designed for 60 Hz [2]. This paper presents the study of transients concerning the motor behaviors of the ship's system supplied by a shore grid with fault current limitation. The simulation studies are established using ATP-EMTP software. The article is structured as follows. The second chapter presents the Shore Connection system topology proposed by

Schneider Electric. The ATP-EMTP system and the simulation results are reported in chapter III and the last chapter sets out the final conclusions.

II. Shore Connection Distribution Grid Topology and Operating Principles

The Shore Connection Distribution Grid represents a harbor solution to supply ships at berth. The system makes the connection between the national grid or the port internal distribution system and the onboard grid. The studied system is shown in Figure 3. The special feature of this solution is the use of Grid Frequency Converters as the link between the 50Hz main grid and a 60 Hz onboard network.

This incompatibility can be solved with a special topology, in which the Frequency Converter acts as a central technology and manages the power demand. According to the standards, the vessels will be supplied with a high-voltage connection. An onboard transformer adapts the high voltage electricity to the ship main switchboard voltage.

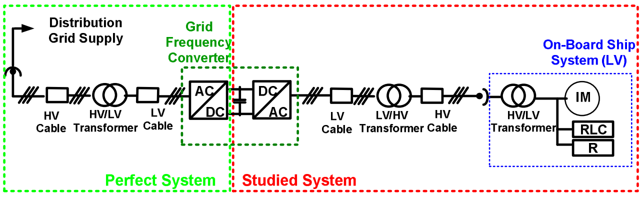


Fig. 3. Shore Connection Distribution Grid topology

In order to obtain a complete view of the studied system, the next sections present each component with its main characteristics and modeling aspects.

a) *Harbour grid and Grid Frequency Converter*

The Grid Frequency Converter (GFC) model is composed of two main converters: a rectifier with a power factor corrector (PFC) and an inverter. In our simulated system, the network between the harbor grid and the DC/AC conversion stage is considered as a perfect grid. The PFC regulation loops are treated like ideal ones, therefore the current and the voltage references on the DC level are fixed. The frequency converter model contains a DC voltage source that supplies the output inverter. The Inverter regulation is modeled with TACS blocks in ATP-EMTP and is made up of an outer slow voltage regulation loop and an inner current regulation loop.

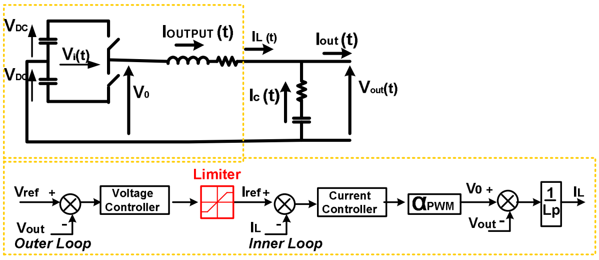


Fig. 4. Control block diagram of the single-phase inverter system

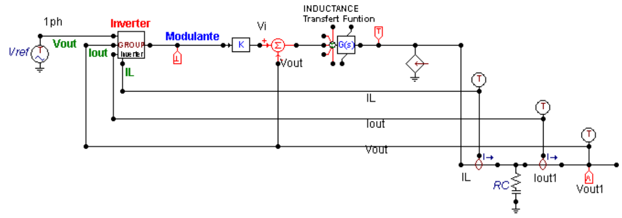


Fig. 5. Single-phase Inverter model in ATP-EMTP

The value of the reference current in the inner loop is limited at an admissible maximal value due to switches thermal constraints. The GFC output current (I output (t)) calculated by the controlled loops is delivered in a TASC current source that makes the link between the TACS blocks and the simple model of power components. The limitations depend on the fault intensity and the availability of the inverter's power. If the fault exceeds a certain duration, the installation switches to standby. As mentioned, the Grid Frequency Converter's behavior must be evaluated in transient regimes (motor turn on/off, load variation) to analyze that limitation period.

b) *LV and HV cables model*

The low voltage cables model (185mm² - 10m) is represented by a symmetrical RL coupled line model. The high voltage cables model (95 mm² -1km) is an LCC model (PI model type), having three phases, with the screen being grounded.

c) *Transformer model*

The proposed system has two 3.15 MVA Dyn11 transformers: one transformer (LV/HV) on the shore side and another step-down transformer (HV/LV) onboard the vessel; both of them are modeled in ATP using the BCTran model. The model takes into account the number of windings, the transformation ratio, and the open circuit and short-circuit data.

d) *Loads model*

The various loads of a ship's network consist of different components, such as lighting, air conditioning, refrigerators, ventilation equipment and hotel loads. These electrical consumers vary throughout the operating period. Thus, it is difficult to estimate an equivalent load. Most of the ship's loads are driven by induction motors on different levels of power, on medium or low voltage.

On the other hand, the simulation time required by the study of a large number of induction motors is very long and the model is too complex. In order to reduce the system's complexity and to simplify the computation for the dynamic behavior of the ship power system, the number of motors is reduced by applying the aggregation method.

The accuracy of the aggregation results may depend on the precise formulation of simplifying assumptions detailed below. Various aggregation models have been proposed by the literature [6], [7]. This paper uses the aggregation method in which the induction motors are connected to a common bus in the power system.

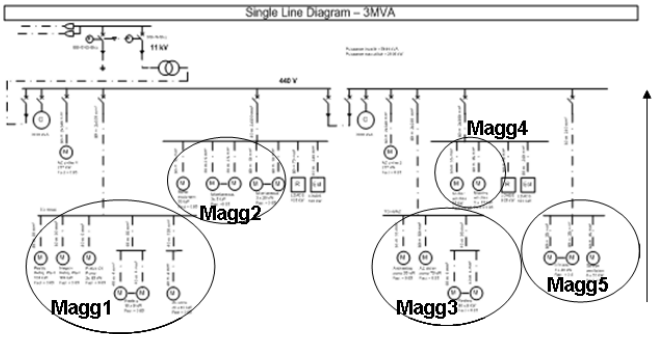


Fig. 6. Ship electrical system

The ship's electrical system has a radial architecture (figure 6). The aggregation method was applied from the farthest point to the common bus. The motors were grouped in five homogenous zones and the aggregation is applied for each motor group. It was assumed that all five aggregate motors were connected to the same common bus. In the second phase the various aggregated models are assembled in a unique aggregated motor model.

The method used for the aggregation motor uses the conventional equivalent circuit model [6]. The design data are taken from the standard motor specifications provided by the manufacturer and then converted, using the WindsynATP software, into electrical parameters.

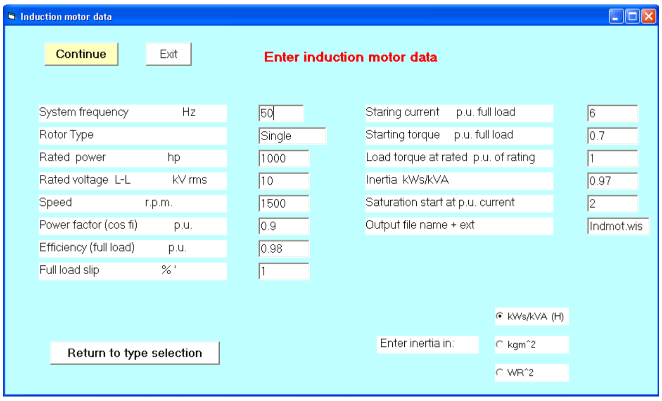


Fig. 7. WindsynATP window

Using this data and applying the following hypotheses, the equivalent circuit parameters of the aggregation induction motor are determined. The first hypothesis and the most significant one is that the motors must be connected in parallel, on the same bus, operating at a common voltage (440V) and frequency (60 Hz). It was assumed that the power and the torque of the aggregate motor are equal to the sum of the power and the sum of the torque of the motors under consideration.

The equivalent circuit parameters are determined by applying two operating conditions: no-load test (slip = 0) and locked-rotor test (slip = 1).

The inertia of the aggregation motor is considered to be:

$$J_{agg} = \frac{\sum_{i=1}^{N} J_i \cdot \omega_i^2}{\omega_{agg}^2}$$

[kgm²][7], with ω_i [rad/s]- the angular speed of the motors under consideration and ω_{agg} [rad/s] - the angular speed of the aggregation motor;

Also, the motors have the same number of poles. This hypothesis about the number of poles is a very important aspect of the aggregation method. The number of poles affects both the synchronous speed and the inertia of an induction motor. Therefore, the number of poles in an aggregate model is chosen in accordance with the application. In the literature, the number of poles of an aggregate motor can be equal to the number of poles of the largest motor among the motors under consideration [9]. This number of poles is calculated like a pseudo number [10]. According to the above, in this paper, it was assumed that $np_{agg} = np_i$, for $i = 1 \div N$.

Rs – stator resistance [Ohm]; Ls – stator inductance [H];

Rr – rotor resistance [Ohm]; Lr – rotor inductance [H];

Lm – magnetizing inductance [H]; s - slip [%];

Un – nominal voltage [V]

N – number of motors to be aggregated.

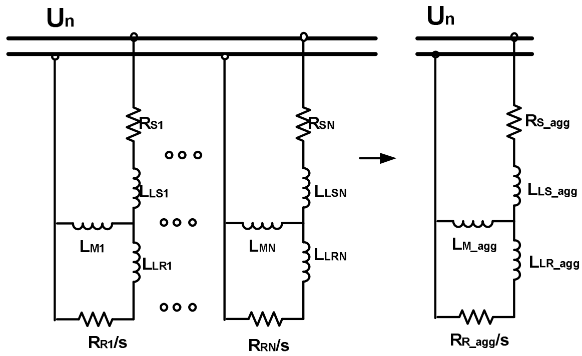


Fig. 8. Aggregation method

In ATP, the aggregate model is simulated using an UM3 model (Universal Machine Model) and the mechanical part is modeled as an electrical circuit. To simulate the transient behavior of the induction motor, it is necessary to represent the load's characteristic. Here, the motor's load is defined as a variable resistor (Voltage = f(Current)). In a steady-state period, the motor's load profile is assumed to be constant.

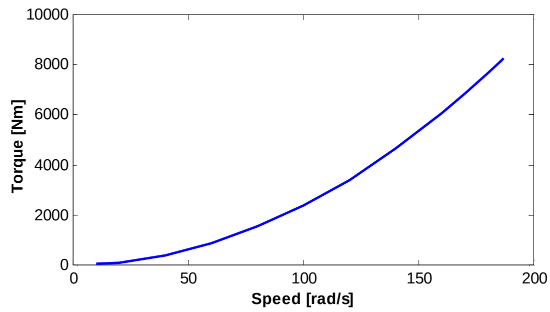


Fig. 9. Equivalent Variable Resistor model

Speed = f (Torque) $\rightarrow$ Voltage = f (Current)

In starting period, the motor use the pumps and ventilation profile: $C = k \cdot \Omega^2$ [Nm]. The voltage is equal with the square of current.

The ship's load system has been divided into three types of load: motors, RLC loads and resistive load.

- Ventilators, pumps, refrigerators: Motors = 1.75 MW
- Other loads: Resistive load = 210 kW
- Lighting: RL load = 380 kW.

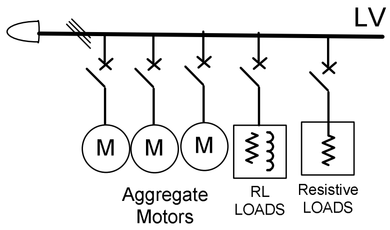


Fig. 10. Ship's Loads

III. ATP-EMTP System and the Simulation Results

A) Steady-state Scenario

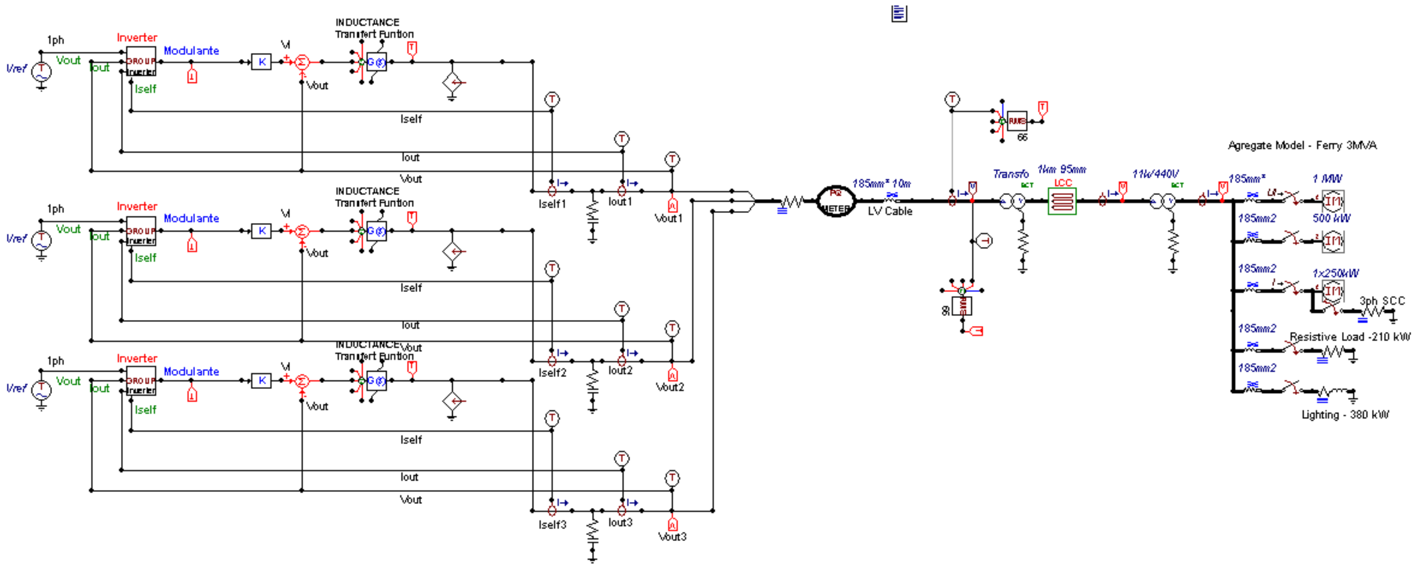


Fig. 11. Simulated system in ATP

The steady state simulation has been carried out to verify the simplified model of a grid frequency converter.

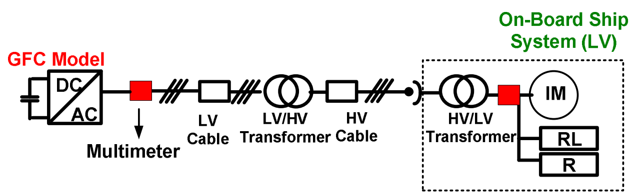


Fig. 12. Steady State System

As shown in figures 13 and 14, the shore station has a stable behavior and delivers the power demanded by the ship.

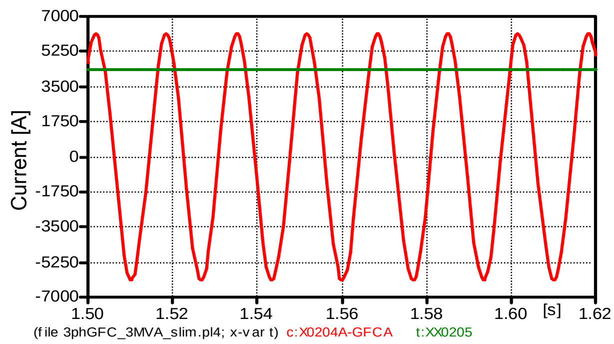


Fig. 13. GFC output current waveforms and RMS value

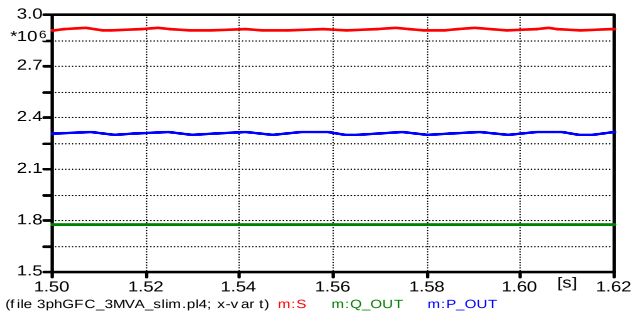
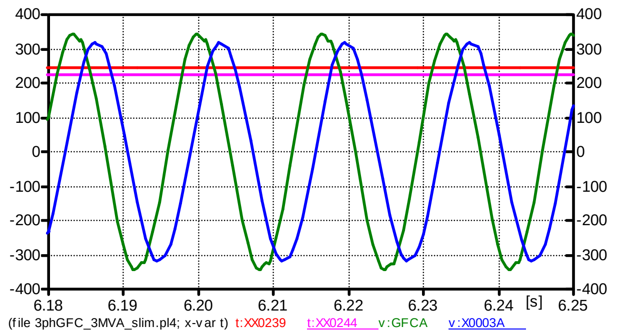


Fig. 14. GFC output power: red - Apparent Power [VA]; blue - Active Power [W]; green- Reactive Power [VAr]



- green: GFC Output Voltage [V]; blue: LV Ship Voltage [V];
- red: RMS GFC Output Voltage [V]; pink: RMS LV Ship Voltage [V]

Fig. 15. GFC output voltage and ship voltage

B) Short-circuit Scenario

A three-phase short-circuit is provoked near a 250kW motor in the ship electrical system. The fault is cleared after 100ms. The impact of this incident affects the shore installation and GFC output voltage decreases by 10%; so the GFC controller detects a current value which exceeds the imposed limitation.

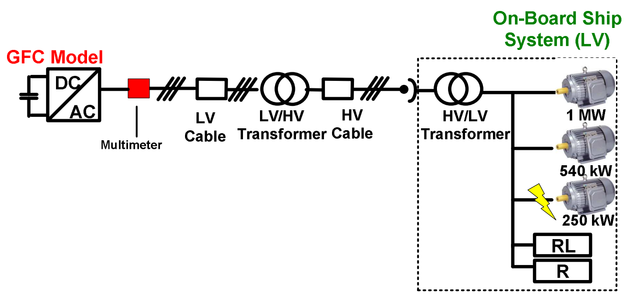


Fig. 16. Short-Circuit System

The effects of the onboard short-circuit are shown in the next figures. The magnitude of the voltage dips depends on the fault location (HV or LV side) and the type of load which is affected by the short-circuit. In this study, it is assumed that the short-circuit occurs on the LV side close to the 250 kW motor (figure 16).

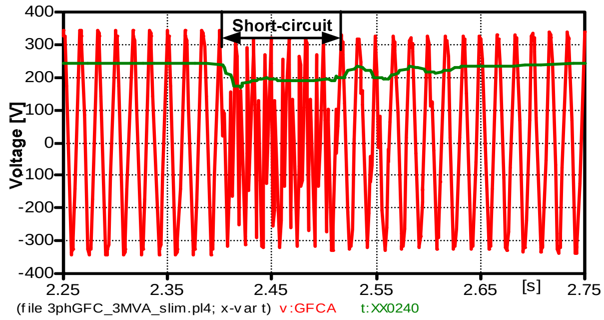


Fig. 17. Behaviour of GFC Output Voltage due to onboard short-circuit

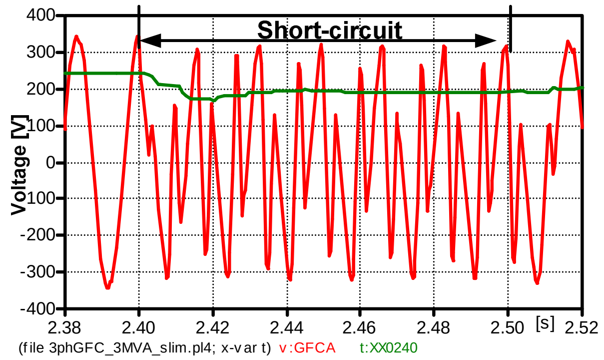


Fig. 18. GFC Output Voltage

In the fault period, there is a large transient current of the order of the starting current which is limited by the Grid Converter Frequency system and the voltage becomes unstable. The fault duration depends on ship protection. If that period exceeds the GFC's protections' time threshold the shore system experiences a blackout.

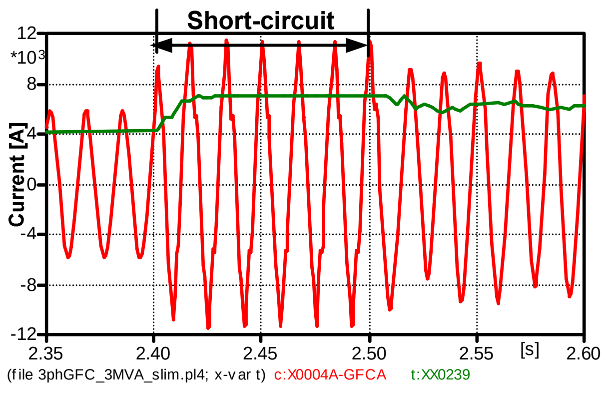


Fig. 19. GFC output current

C) Starting Motors

In order to verify the GFC limits of a 3MVA installation, in Motor Direct-On-Line Starting, three different motors were tested: an aggregate motor of 500 kW and two others of 1MW and 1.5 MW (table 1). This test provides that the onboard system is operating normally, all the loads are active, and only one motor will start on direct line at t=3s.

TABLE I. AGGREGATE MOTOR DATA BASE

Motor [kW]	500	1000	1500
No.agg.motors	2	49	66
Torque [Nm]	4322	5800	8272
Inertia [kgm²]	8	10	50
Rs [Ohm]	0.006656	0.0141	0.0105
Ls [H]	7.6E-5	2.477E-5	1.727E-5
Rr [Ohm]	0.00973	0.0099	0.0059
Lr [H]	7.6E-5	2.477E-5	1.727E-5
Lm [H]	1.67E-3	0.708E-3	0.514E-3

- Start-up of a 1500kW aggregate motor on a 3MVA vessel

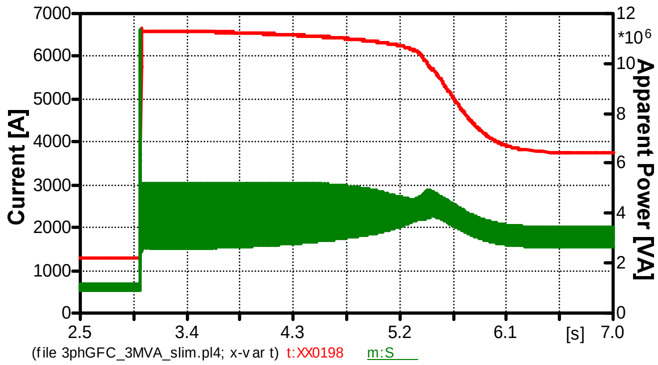


Fig. 20. GFC Output RMS Current & Apparent Power

- Start-up of a 1000kW aggregate motor on a 3MVA vessel

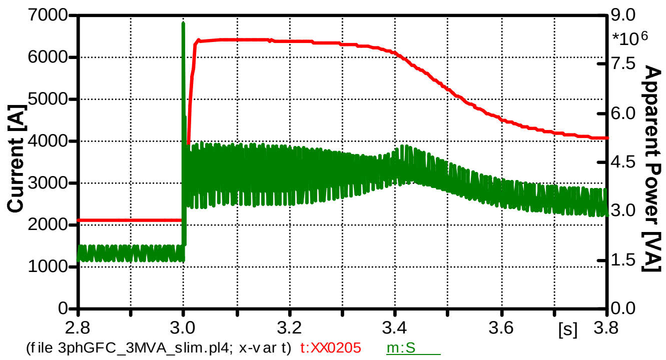


Fig. 21. GFC Output RMS Current & Apparent Power

- Start-up of a 500kW aggregate motor on a 3MVA vessel

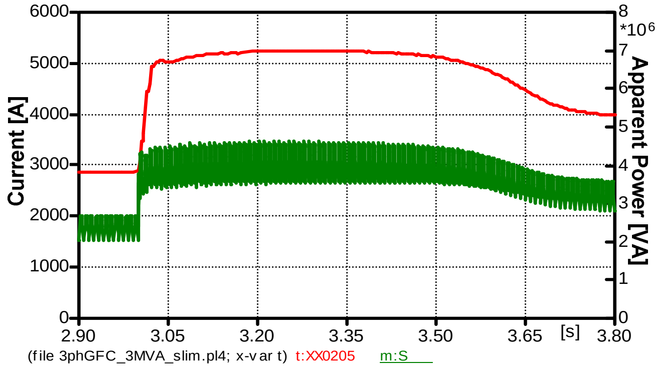


Fig. 22. GFC Output RMS Current & Apparent Power

By starting the motors and analyzing the simulation results, it can be seen that direct starting of a 500 kW motor is suitable for a 3MVA shore system. The starting current is lower than the GFC limit. With the 1000 kW motor, the situation becomes much more critical, because the starting current reaches the limits imposed by the frequency converter system. The limitation period for starting a 1000 kW motor is dependent on the inertia value, so it depends on the load type. For the third case, direct starting of a 1500 kW motor is not feasible for a restrictive system like the shore grid. The limitation period is very long and it is not admissible for correct operation.

IV. Conclusions

This work presents the steady state and the transient behavior of a current-limited system that powers a ship's electrical system. The proposed system can be applied to industrial grids with a large number of induction motors. The aggregate motor models have been modeled to simplify the complexity of a ship's system. To study the interaction between the shore supply system and the onboard network, the paper describes the shore-to-ship components modeled in ATP-EMTP. The proposed models take into account the main characteristics of the physical behavior, but also try to simplify the complex system by applying a few hypotheses. The aim of this study was to analyze the behavior of a shore-to-ship system in steady state or in transient cases.

V. References

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