Transient studies of Fault Current Limiters in ship power systems with PSCAD.

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Compared to today's navy ships, the electrical power generation on future all-electric navy ships is significantly increased. Consequently, this leads to higher short-circuit currents in these ship's power system. This is particularly valid for the main generators of ships power systems non controlled by Power electronic devices, involving high fault current levels. In low voltage systems (typically up to 480 V) fault current limitation can easily be achieved by means of electro-mechanical current limiting circuit breakers. For medium and high voltage systems, utility companies apply measures such as splitting grids into sub grids, splitting of bus bars, introducing sequential breaker tripping schemes, increase of voltage levels using high impedance transformers, or adding current limiting air core reactors. Up to 36 kV and rated currents of a few hundred amps, high voltage fuses are also used. For higher rated currents up to this voltage class explosively triggered fuse-based systems such as the IS-limiter [1] have been developed and deployed. However, all these traditional measures have significant disadvantages: they either introduce significant impedance permanently (e.g. adding reactors) or they require maintenance after a fault event (e.g. fuses) without the ability to auto re-close after fault has been cleared. That is why a number of novel fault current limiter (FCL) technologies for the medium voltage range (< 36 kV) have been developed and proven technically feasible by means of testing prototypes and limited field tests. Transient simulations of such a system have been performed with the well known electromagnetic transient sofware PSCAD/EMTDC. This paper investigates the application of novel FCL technologies for navy ships focusing on simulations aspects.

I. Navy Type Ship Power System Model

The ship power system used for the study outlined in this paper is shown in figure 1. This is typical and representative of a future all electric navy destroyer class ship. The 13.8 kV propulsion level of the system is modeled in detail and the loads at lower voltages are represented using simple lumped resistive or inductive elements. The fault current levels in the low voltage distribution level will be substantially smaller due to the presence of the transformers.

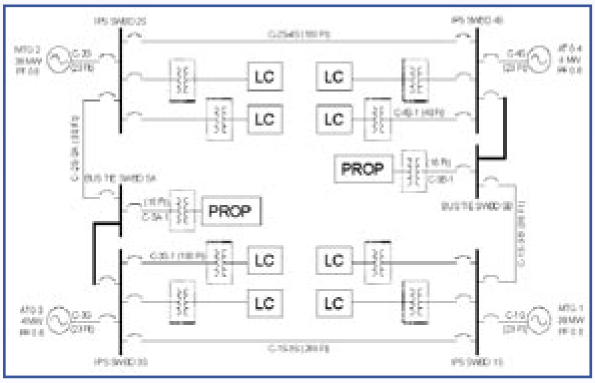

Fig. 1: National power system layout of an all-electric navy ship.

Main components of the power system are four gas turbine driven generators, two main turbine (MTG) and two auxiliary turbine generators (ATG), four integrated power system switchboards (IPS SWBD), two propulsion systems (PROP) that are connected to bus tie switchboards, and four ship service load centers (LC). The MTGs each have a rated power of 36 MW and the ATGs have 4 MW. Each propulsion system consists of an induction motor, a pulse width modulation (PWM) drive and a transformer. The rated power of each propulsion system is 36.5 MW.

As described in more detail in [2] the optimal placement of FCLs for the system depicted in figure 1 was found to be at the main turbine generators only, as shown in Figure 2. This arrangement only requires 2 FCLs to protect the system from excessive fault currents.

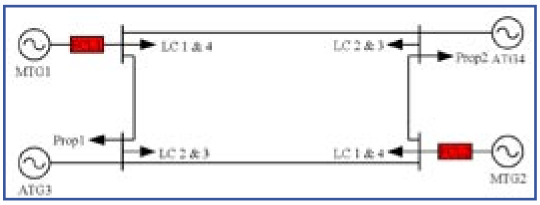

Fig. 2: Optimal placement of FCLs in the system shown in Fig. 1.

II. Fault Current Limiter Model

The most promising FCL technologies developed and tested to date are those based on solid-state devices and those based on super conducting technologies. figure 3 shows a simplified representation of a solid state FCL. Superconducting fault current limiters (SCFCL) take advantage of a superconductors transition from the superconducting to the normal state (quench) due to a current exceeding its critical current resulting in a quick increase of

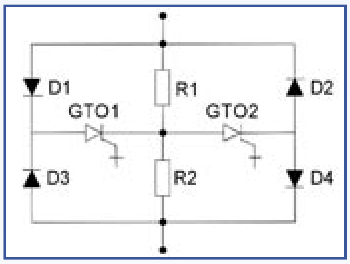

Fig. 3: Simplified electrical circuit of a solid-state current limiter.

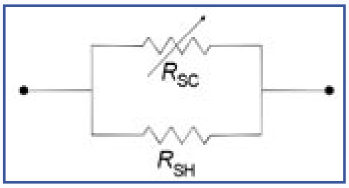

Fig. 4: Equivalent electrical circuit for one element of a superconducting fault current limiter.

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its resistance by several orders of magnitude. In order to protect the superconductor from damage (over-voltage and local overheating, i.e. hot-spots) a shunt resistor RSH is connected in parallel to carry the majority of the fault current as shown in figure 4. During normal operation the resistance of the superconductor RSC is almost zero and the operating current flows only through the superconductor. In case of a fault when the current exceeds the superconductor's critical current the superconductor quenches and the current commutates to the shunt resistance.

In order to investigate the impact of fault current limiters on the performance of the all-electric ship's power system, a generic fault current limiter model was developed and simulated in PSCAD. The model is based on the circuit shown in figure 4 and assumes a nearly exponential rise of RSC from zero to a very large value at a pre-set time after the fault current has exceeded a pre-set threshold value. A more detailed description of the model can be found in [2]. This generic FCL model was validated against test data given in [3].

III. PSCAD SIMULATIONS

Figure 5 shows the detailed PSCAD/EMTDC model of one of the propulsion drive units including the rectifier and the inverter. Additionally, a passive series filter and a passive shunt filter are placed on the supply side of the front end transformer in order to help mitigate voltage distortions caused by the PWM switching. The inverter bridge is controlled directly through PWM modulation of the reference voltage signals. A basic control scheme for the control of the bridges is also shown.This simulation will yield accurate results but requires small time step size to capture the fast switching events. Therefore, for the purpose of this FCL study, a simpler average load model was developed and was validated against the detailed model. The real power drawn by the load is measured and drawn from the supply side of the drive with the variable power load component. This arrangement is shown in figure 6, whereas figure 7 compares results from the two models by means of the voltage and current in phase A at the 13.8 kV bus supplying the propulsion unit.

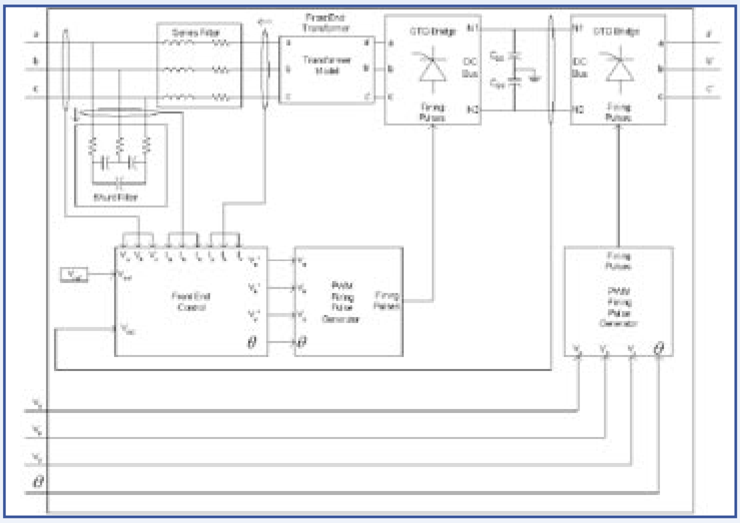

Fig. 5: Detailed PSCAD model of the propulsion drive system.

Figure 8 shows the results for a three phase short circuit at IPS-SWBD1 (compare figure 1). The 1.4 W chosen for the FCL limited the fault current at the main generators. The impedance rise time selected was 2 ms. In addition to limiting the fault current, the additional resistance also causes the system time constant to change which in turn causes the DC component of the fault current to decay faster. This effect may eliminate some CT saturation issues in the protection circuits and is an added advantage. The increased real power drawn from the generator during the fault is shown in figure 9. This is due to the increased losses introduced by the FCL shunt resistance. Note that the long duration of the fault shown here is a choice in the simulation. In a real-life situation the fault would be cleared after 2-3 cycles by the appropriate action of the protection system.

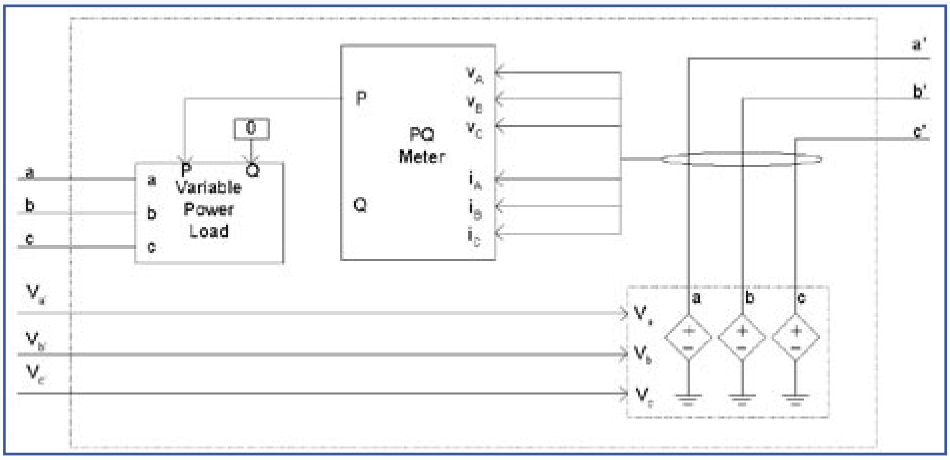

Fig. 6: Average Model for Propulsion Motor Drive.

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Since shipboard power system are typically operated as ungrounded systems there exists a possibility of reducing weight and size of the FCL by implementing the limiting circuitry only on two of the three phases. Figure 10 shows the simulated results of two different fault conditions when the FCL has active elements only in phases A and C. In both cases, the fault inception time was identical. The fault currents are different depending on the phases involved.

IV. Concluding Remarks

In this study the application of fault current limiters on future all electric navy ships was investigated. Specifically, transient simulation models were developed in PSCAD/EMTDC to represent the ship power system. For system studies, a generic fault current limiter model was developed and validated against actual data. Generic fault current limiter were used to simulate different fault scenarios and the results were presented.

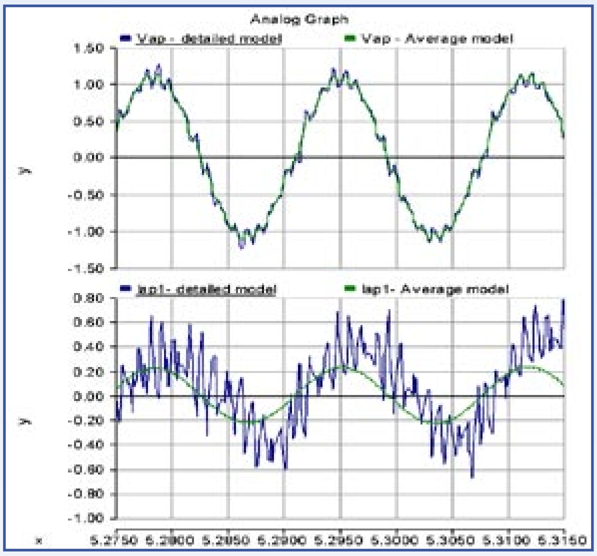

Fig. 7: Comparison of results from the detailed switching model with those from the average load model.

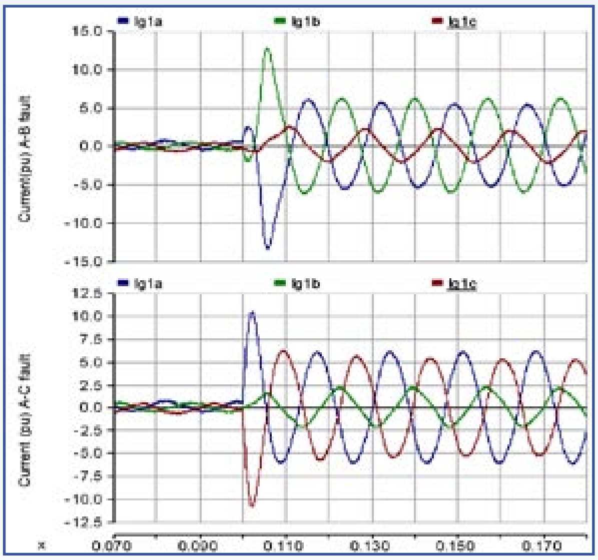

Fig. 8: Unlimited and limited fault current contribution for the main generator #1 for a 3-phase fault.

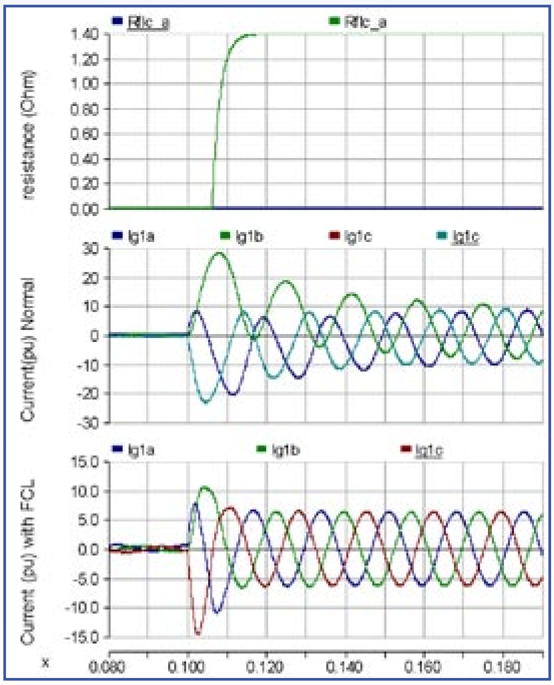

Fig. 10: Main generator current during A-B and A-C faults with the FCL active in phases A and C only.

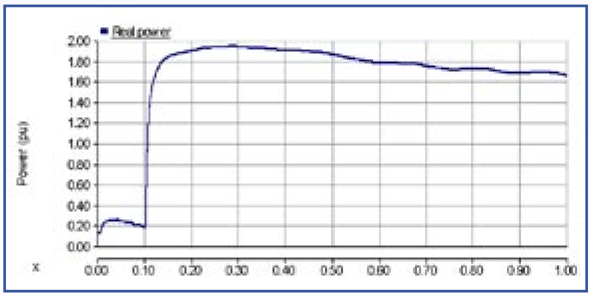

Fig. 9: Real power drawn from the main generator during the fault.