

MODELING OF NAVAL SHIPBOARD POWER SYSTEM WITH MATLAB/ SIMULINK

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ABSTRACT

Field studies conducted have shown that most faults on Naval Shipboard Power Systems (NSPS) lead to short-circuit. When such situation occurs, heavy current flows through the equipment, thereby causing considerable damage to the equipment and interruption of services in the ship. To conduct fault studies on NSPS, an effective simulation tools can be very helpful towards developing an understanding of the dynamics of short-circuit faults and then evaluating the effectiveness of various solution alternatives. Matlab is a powerful tool which has a power systems blocksets/ simulink for modeling and simulation of all power system components. In this study, modeling of NSPS with Matlab is presented. Details of the system components model are explained and the transient behaviours of the system under two cases are presented.

Keywords: NSPS, line faults, Simulink, Matlab

1. Introduction

This research was conducted on SS KYANYA Ship, which was transferred to the Nigerian Navy on 20 December 2002 under the United States Security Assistance Program managed by the Office of Defense Cooperation at the American Embassy in Abuja, Nigeria. Since then, this rugged and dependable ship is being employed to patrol Nigerian territorial waters to protect fishing interests and to check illegal bunkering of oil. The power system configuration of this Naval ship is ungrounded delta type, which ensures continuity of power system. To conduct system studies, such as fault analysis, system reconfiguration/ restoration, etc., for NSPS, an effective simulation tools is needed. In literatures, there is no exact tool that must be used to simulate shipboard power systems. Matlab has proved its modeling and simulation capability in many power system literatures [1,2,3].

The following section discusses NSPS configuration briefly, Section 3 discusses; test circuit, Powerlib modeling and case studies in detail. In section 4, results of the test cases are explained with illustrative waveforms. Finally, concluding remarks are presented in the subsequent section.

2. Naval Shipboard Power System Configuration

The electric power grid of a ship can be regarded as a small scale industrial power system [4]. A ship's electric energy system consists of a generator set and a distribution cabling system serving the loads. In the case of a conventional ship's power system, there are at least two main AC generators driven by diesel engines, gas turbines or the main propulsion engine.

Power is supplied to the electric loads consisting of:

- the conventional auxiliary systems similar to an industrial plant (lighting and motors driving rotating machinery)
- the main and auxiliary ship propulsion systems.

The generated voltages are at level of 450V a.c and frequency of 60Hz. The ring bus configuration is mostly employed in naval ships; this is to ensure continuity in power supply to vital loads whenever failure of an operating generator unit occurs [5]. This feature is of great importance in order to ensure supply of power to vital loads if failure of an operating generating unit occurs. Generators are connected to switchboards called generator switchboards, which are composed of one or more switchgear units and breakers for various devices like the generator, loads and load center switchboards. These generator switchboards are located close to their associated generators. Bus bars interconnect the generator switchboards which allow for the flow of power within the switchboards

Ship generators/switchboards are placed on different levels (floors) and are horizontally displaced along the ship to prevent total outage during battle. There are three major types of navy ships utilized during battle: submarines, surface combatants and aircraft carriers. Generally, a combatant type ship consists of a three generator system in the ring configuration; two of the generators would be used for normal operation with the remaining generator serving as emergency supply [5].

The other components of navy electric power systems are load center switchboards, power distribution panels, bus transfer units, transformers,

and interconnecting cable used for delivering power to the loads. Load center distribution, which is a modification of radial distribution, is used below the generator switchboard level. One or more load center switchboards are connected to each generator switchboard to supply power to load concentrations in various areas of the ship. The load center switchboards supply power to power panels or individual loads, either directly or via automatic bus transfers (ABTs) or manual bus transfers (MBTs). Power distribution panels are centrally located to the loads that they feed. They provide control and protection of selected portions of the power for lighting distribution systems and special power distribution systems.

Loads are fed directly from generator switchboards, load centers or power distribution panels. The loads require power at 440, 115, and 4,160 volts at 60 hertz, and 440 and 115 volts at 400 hertz. The loads requiring 400 hertz are typically part of the command and surveillance systems, weapons systems, and aircraft and aviation support equipment. The 4,160 volt loads are typically associated with aircraft carriers. Transformers are used to convert supply voltage of the distribution system from one level to another. The interfaces used between the 60 hertz and 400 hertz systems are either motor-generator sets or static solid-state frequency converters (SSFCs) [5].

Although power systems found in navy ships appear simpler than their commercial terrestrial counterparts, shipboard electrical systems have unique characteristics that demand special attention during design and when performing other kinds of investigations, such as fault studies [5].

The protection system must perform efficiently in selectively isolating only loads affected by fault conditions and provide for reconfiguration to restore service as quickly as possible.

In this paper, a simple test system composed of navy power system component models was developed to conduct simulations.

3. Test Circuit Description, PowerLib Modeling and Case Studies

3.1. Test Circuit Description

The test system includes ungrounded three-phase delta-connected Generator (G) 12 KVA, 450 V line-to-line, 60 Hz, Transformer (T) of 2KVA, 450/115V line-to-line, Delta-to-Delta connected, Load (L1): 5kVA, PF = 0.90, 450 V line-to-line, balanced, Delta-connected and Load (L2): 1.9kW, PF = 0.95, 115V line-to-line, balanced, the Generator is connected to a switchboard by a 5.2-meter long cable, and a 10.4-meter long connecting the load center L1 to the generator switchboard. Both cables were three

phase, and the cable system was modeled as two meters above the ground. A lumped three-phase LR meters above the ground. A lumped three-phase LR load, L1, ($R=8.11\Omega$, $L=11.338\text{mH}$) is connected to load center L1. A three-phase, 450/115 V transformer T with three-phase delta-connected resistive load L2 ($R=123.35$ ohms) is also connected to the load center. Fig.2 (b) is the Power System Blockset model of Fig.2 (a) in which the generator and load centre switchboards are modeled as Buses B1 and B2.

3.2. PowerLib Modeling

A system consisting of components of a typical NSPS of fig.2(a) is modeled and simulated with Power System Blocksets of Power Library (PowerLib), connected in Simulink environment of Matlab 6.0.

These components include navy cable, delta-connected three-phase generators, delta-connected three-phase transformer banks, circuit breakers, loads, buses (generator switchboards, load center switchboards, and power panels), and monitoring elements. PowerLib uses linear, discrete, passive and active electrical elements, etc. for network simulation [6]. Systems are built by combining components in an electrical model, called a Simulink environment. The following sub-section discusses how these components are modeled in PowerLib.

3.2.1 Modeling of NSPS components in Powerlib

I. Generator Model

This generator block implements a three-phase source in series with a series RL branch. The common node (neutral) of the three sources is ungrounded, since Shipboard Power Systems are ungrounded. The parameters of the generator model include: Phase-to-ground Peak voltage, Phase angle of phase A, frequency, source resistance and source inductance which are assigned by the users. The ports of the generator symbol are the three phase generator terminals with ungrounded neutral.

II. Transformer model

Three-phase transformer block of two windings, is modeled by using three single-phase transformers. The two windings are set to Delta connected, thereby making the transformer delta-connected. The parameters of the transformer model include: Nominal power, frequency, V_{rms} , Resistance and Inductance of the primary and secondary windings, also included are the magnetization resistance and reactance of the transformer.

III. Bus

B1 and B2 Blocks are three-phase V-I Measurement blocks taken from the Extra/Measurement library. The blocks are programmed to accommodate 3-phase input and 3-phase output.

They measured three line-to-ground voltages multiplexed on output 4 and the three line currents multiplexed on output 5.

IV. Circuit Breaker/Switch (CB)

Generator switchboards are composed of one or more switchgear units and breakers for various devices like the generator, loads, and connected load center switchboards. These generator switchboards are located close to their associated generator. In this study, a switchboard along with the associated circuit breakers/switches is modeled as a single unit. The parameters of the switchboard include the parameters of circuit breaker or switch. The parameter of the 3-phase breaker/switch include; initial status of the breaker, transition time, sample time of the internal timer, breaker resistance, snubbers resistance and capacitance.

V. Three-Phase Fault

This block was used to program a fault (short-circuit) between any phase and ground. The parameters of this block include; fault and ground resistance, transition status and time(s), sample time of the internal timer, snubber resistance and capacitance. Short-circuit fault between lines was programmed by checking the appropriate boxes that contain the phases and ground.

VI. Load model

The loads are represented by the real and reactive impedance components connected in star. It is a three phase symmetrical constant impedance load. The parameters include Nominal phase-phase voltage (rms), frequency, 3-phase active and reactive power of the load. Other loads such as motors will be modeled in future work.

To build a system from the PowerLib models in Matlab, the appropriate models are dragged to the simulink window and are interconnected to create the system network. Input parameters are entered for each component model to

appropriately define it according to the specifications of the system.

3.3. Measuring and Output Devices

Most of the simulink measurement and output devices are located in sinks library and measurement blocks of PowerLib [7]. The devices of interest can be marked in the schematics for these purposes. After or during simulation, the scopes and other output block can be activated by double-clicking to give the waveforms of the measured parameters. The scope can be used as single input of multiple input, depending on the user's specification. It also has the capability to accept multiplexed signals from a single input terminal. Even the parameters that are not marked in the schematic are available for monitoring in the Powergui (power graphical user interface) block, which consists of all branch currents and all node voltages. These can also be assessed by double-clicking the block

C. Case Studies

In this study, two different cases were developed to analyze the given test system under fault conditions:

- Case 1: Normal system operation (no fault).
- Case 2: Single-Line-to-Ground (SLG) fault for test system.

For the test system, the following parameters were monitored as shown on Fig. 2(a) and 2(b).

V_{ab}, V_{bc}, V_{ca} : line voltages of the transformer primary side shown in Fig.2(b)

$V'_{ab}, V'_{bc}, V'_{ca}$: line voltages of the transformer secondary side shown in Fig.2(b)

I_{ab}, I_{bc}, I_{ca} : 450V load currents shown in Fig. 2(a)

$I'_{ab}, I'_{bc}, I'_{ca}$: 115V load currents shown in Fig. 2(b)

I_a, I_b, I_c : Transformer primary line currents shown in Fig. 2(b)

I'_a, I'_b, I'_c : Transformer secondary line currents shown in Fig.2(b)

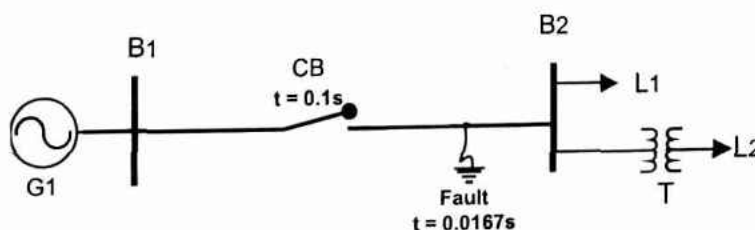


Fig 1 (a): One line circuit diagram for the test system

G1= Generator 450V, 60Hz CB = 3-phase Circuit breaker
T = Transformer, 450/115V delta-delta connected L1,L2 = Delta connected loads
B1& B2 = Generator and Load centre Bus bars respectively

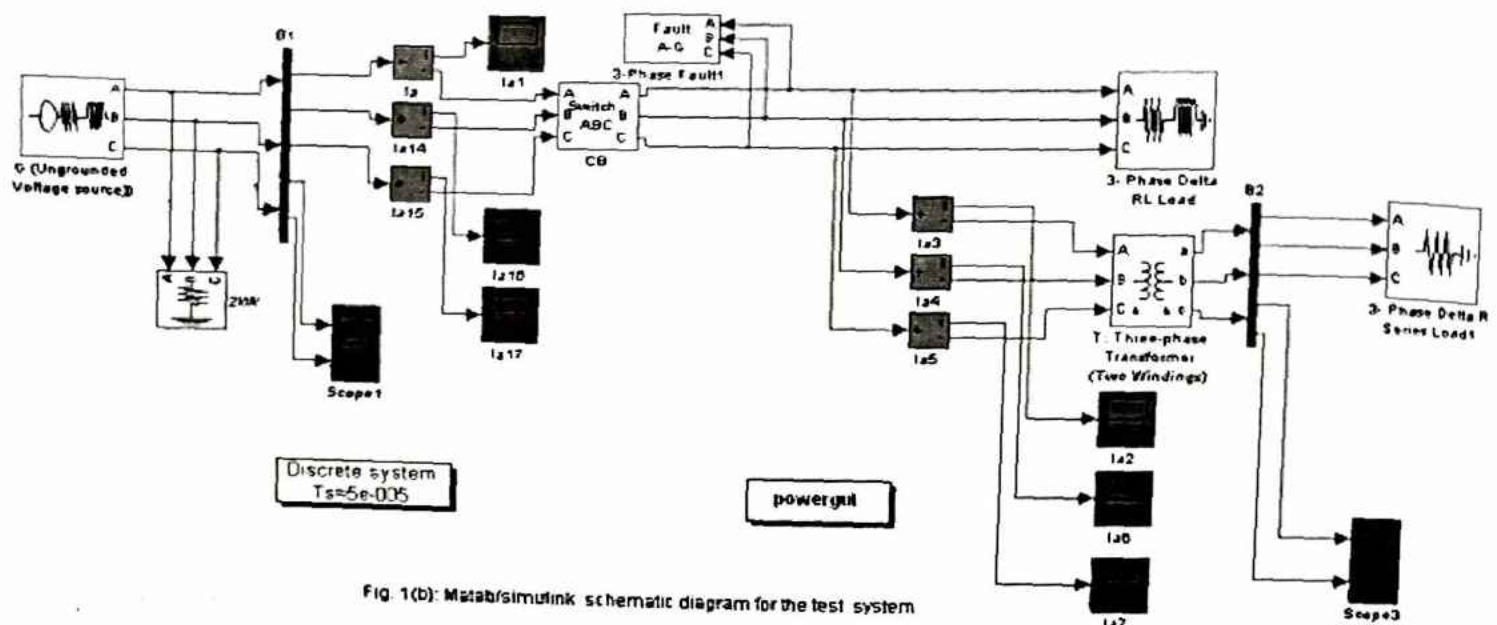


Fig. 1(b): Matlab/simulink schematic diagram for the test system

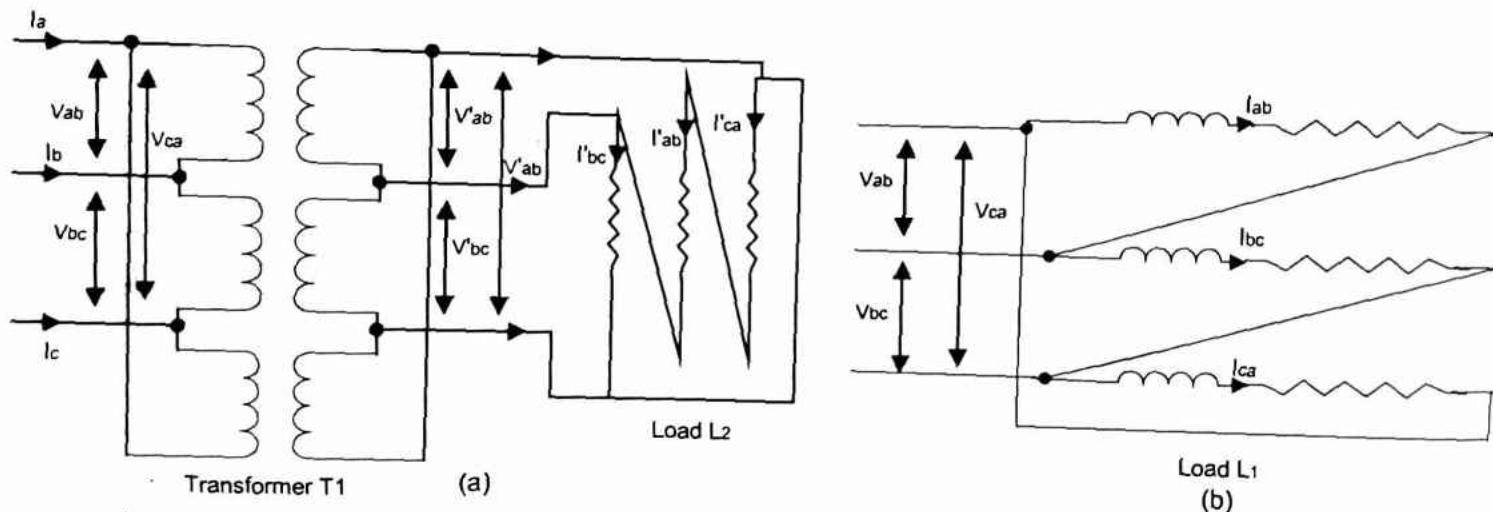


Fig.2: Circuit diagrams of transformer and loads of the test system

4. Results and Discussion

In the following result discussion, two cases were considered with illustrative waveforms. Each case is explained with waveforms.

The simulated parameters used for two cases are as follows; simulation time- 0.2second, solver options- Fixed-step with discrete of a defined $T_s = 50e-6$ in auto mode.

Here, we studied the transient behaviour of NSPS network of fig. 1 under no-fault condition (normal operation) and when SLG fault is applied on 'line a'. The fault and the circuit breaker (Switch CB) are simulated with blocks from Powerlib.

Case 1

The waveform of fig. 3 and fig. 4 represents automatic measurement steady state voltages and current were observed by clicking Powergui. It was found that the steady state value for each monitored parameters is calculated as expected. As shown in fig.3 and fig. 4, the transformer peak primary and secondary voltages measured at Bus 1 and Bus 2 are 632 and 161.5, which implies that the Voltage ratio is $632/161 = 3.9133$. from the ratings, the Voltage rating is $(450/115) = 3.913$. Therefore putting the percentage error to about 0.008%. This is an indication of Matlab exceptional accuracy in power system

simulation. These error is similar to all other measured parameters

Case2

At time $t = 1$ cycle, SLG fault was applied to 'line a'. As shown in fig.7, at instant of the fault V_{ab} decreases nearly to zero while other line volatages V_{bc} and V_{ca} doubled their initial peak values, these are transformer primary voltages. Fig.8 shows transformers secondary line voltages and it could be seen that these voltages were not affected by the SLG fault. Fig.9 shows the comparison between V_{ac} in normal operation and fault condition.

Fig.10 is a depiction of transformer line currents under SLG fault. Fault current in 'line a' increases to 30A (triple the normal operating current)

while currents in other lines increases by half of their initial peak values during the SLG fault period. Also, in fig.11, the appearance of the transformer secondary voltage signals depict that they are affected by the fault. Fig.12 shows the comparison between I_a in normal operation and fault condition. Therefore, the spikes are observed at end of fault time due to the opening of line breakers.

Based on the illustrated simulation results of Case 1 and Case 2, it is obvious that ungrounded delta configuration ensures normal voltage supply even in the presence of SLG fault on any line, and this is a major reason why almost all naval ship constructors adopt delta configuration .

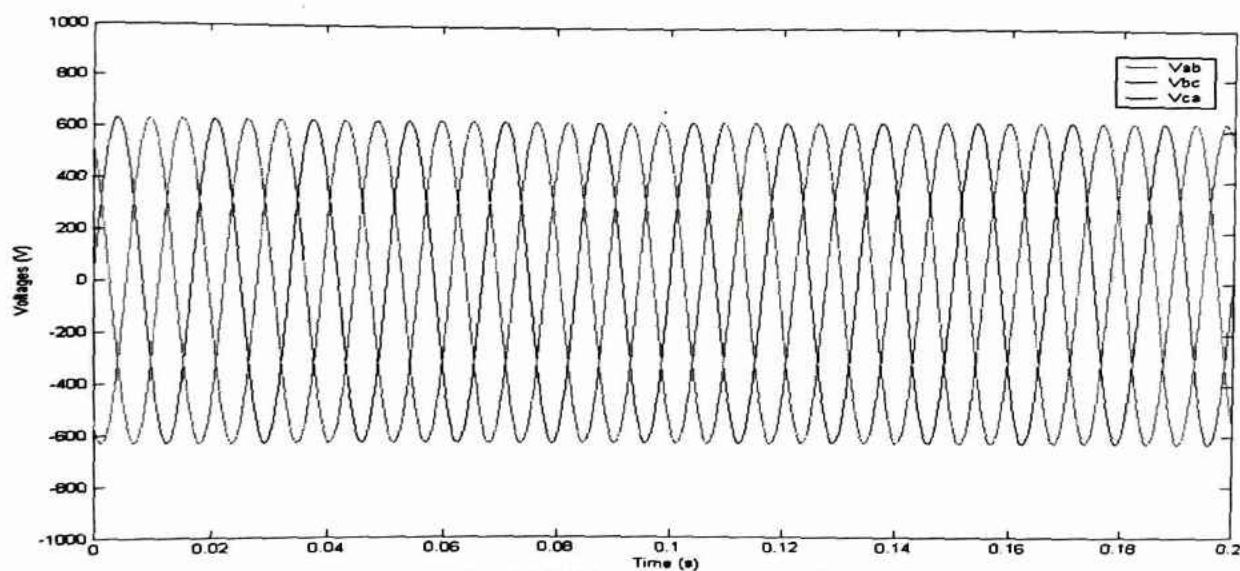


Fig 3: Case1- Primary Voltages of the Transformer

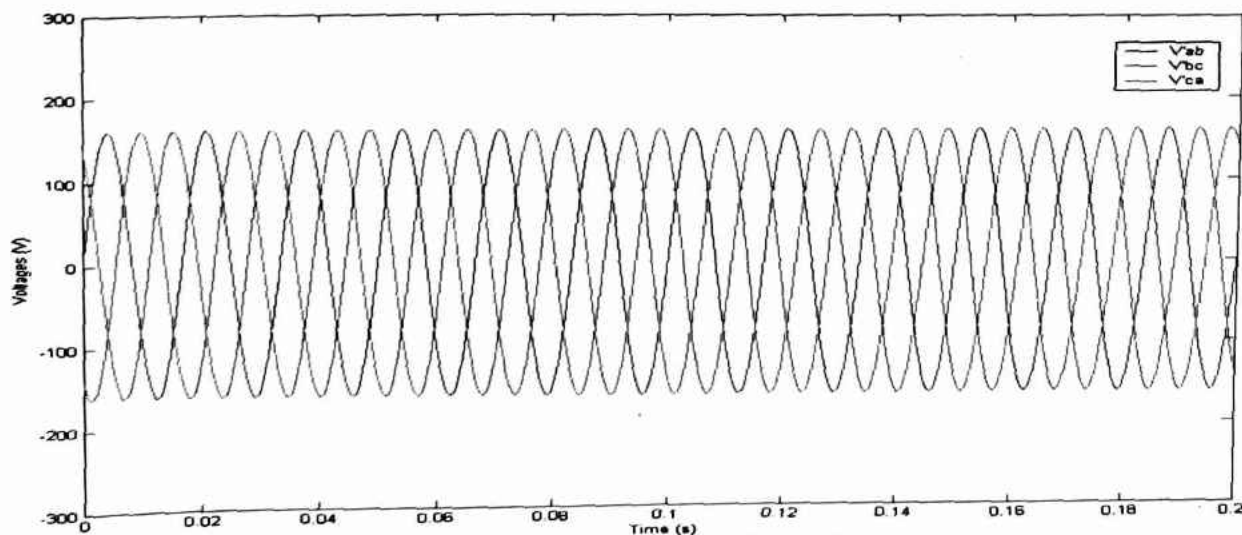


Fig 4: Case1- Secondary Voltages of the Transformer

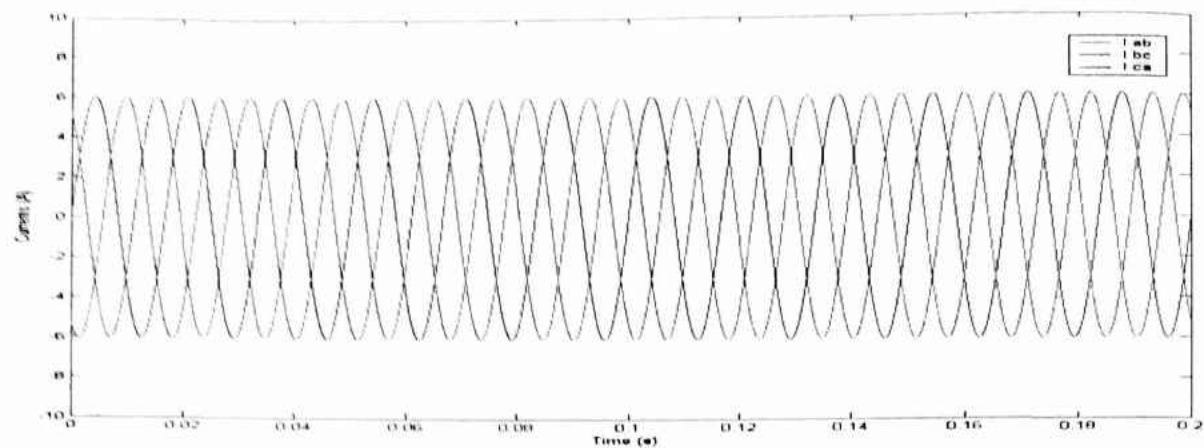


Fig 5: Case1- Transformer Primary Currents

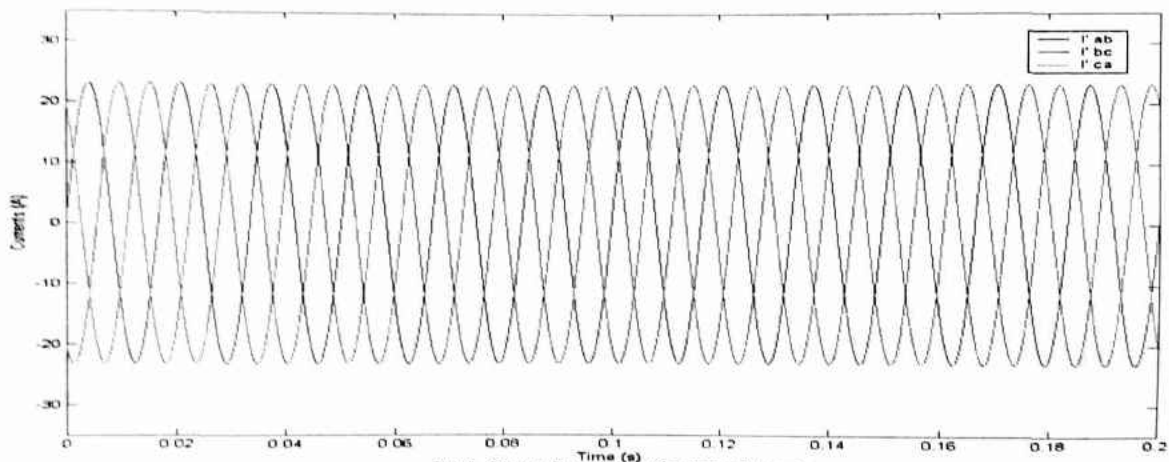


Fig 6: Case 1- Transformer Secondary Currents

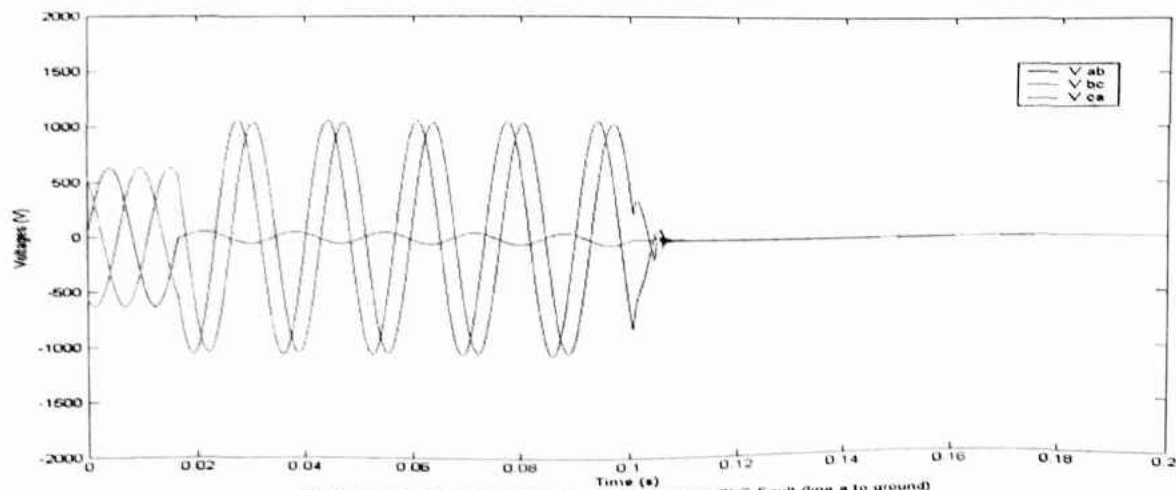


Fig 7: Case 2 - Transformer Primary Voltages Under SLG Fault (line a to ground)

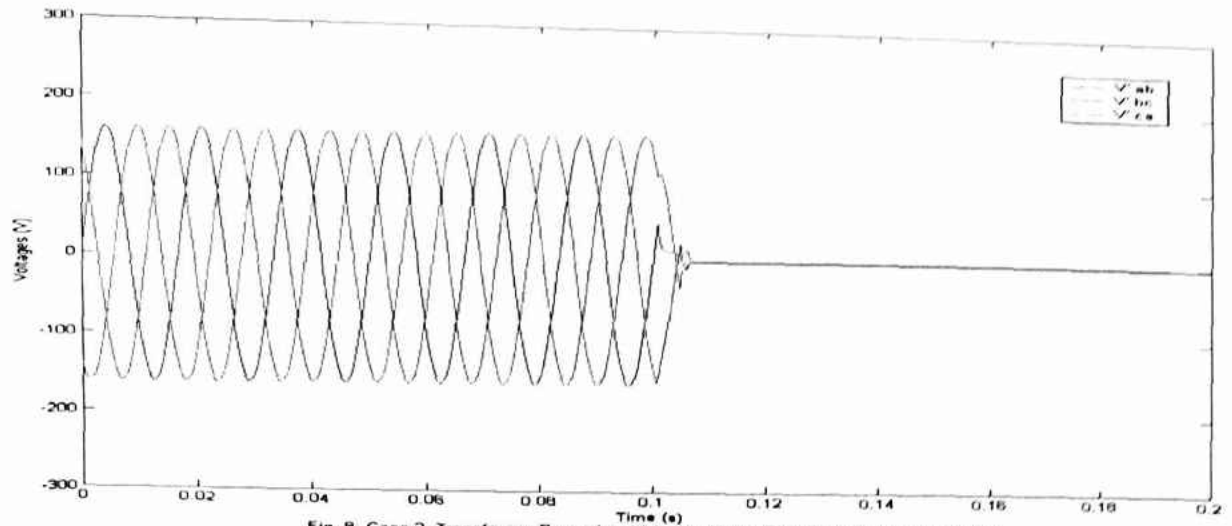


Fig. 8: Case 2- Transformer Secondary Voltages Under SLG Fault (Line a to ground)

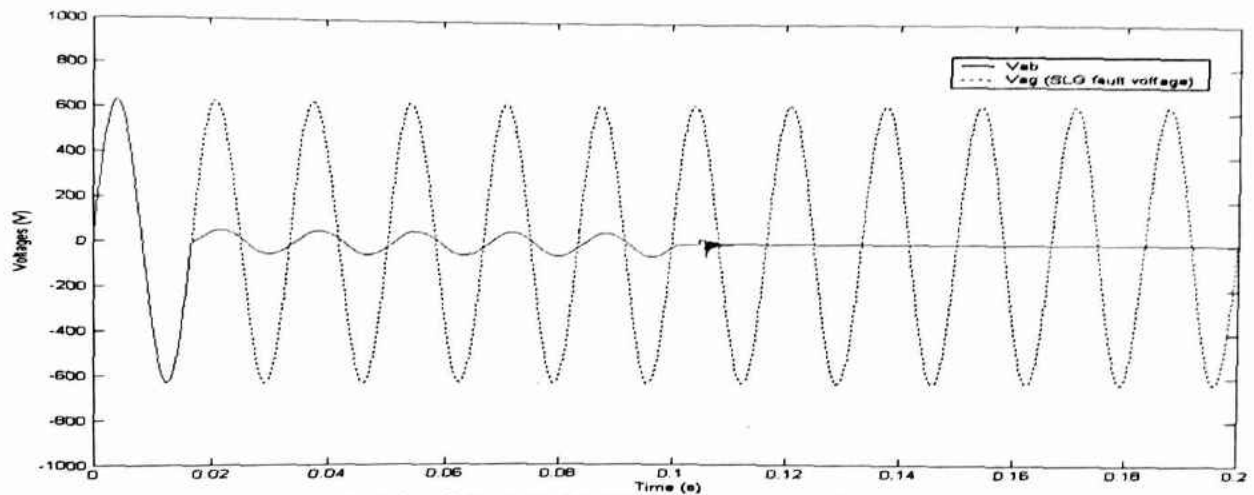
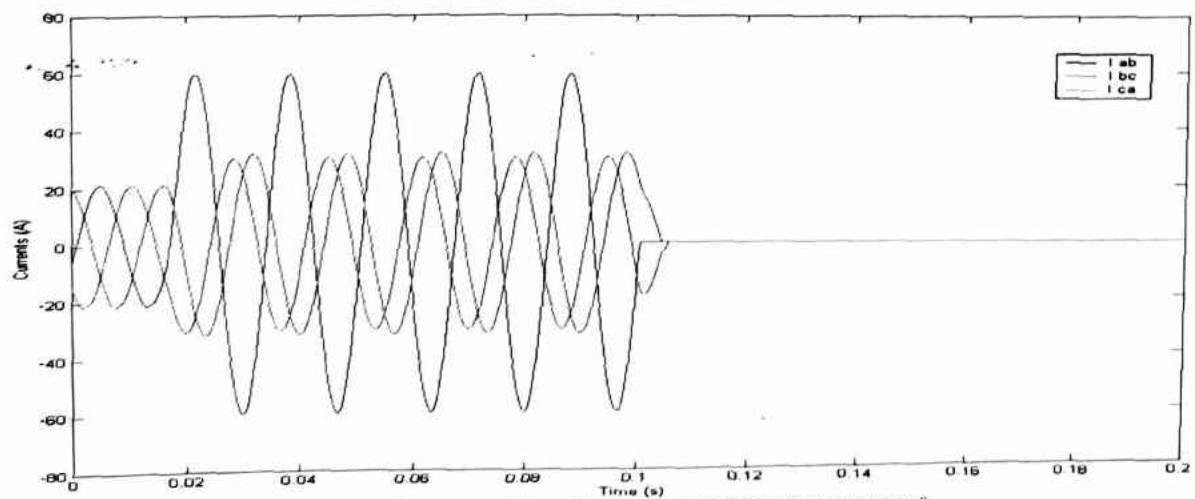
Fig.9: Case 2- Line-to-line Voltage V_{ab} and Line-to-ground Voltage V_{ag} (fault voltage)

Fig.10 Case 2: Transformer Primary Currents Under SLG Fault (Line a to ground)

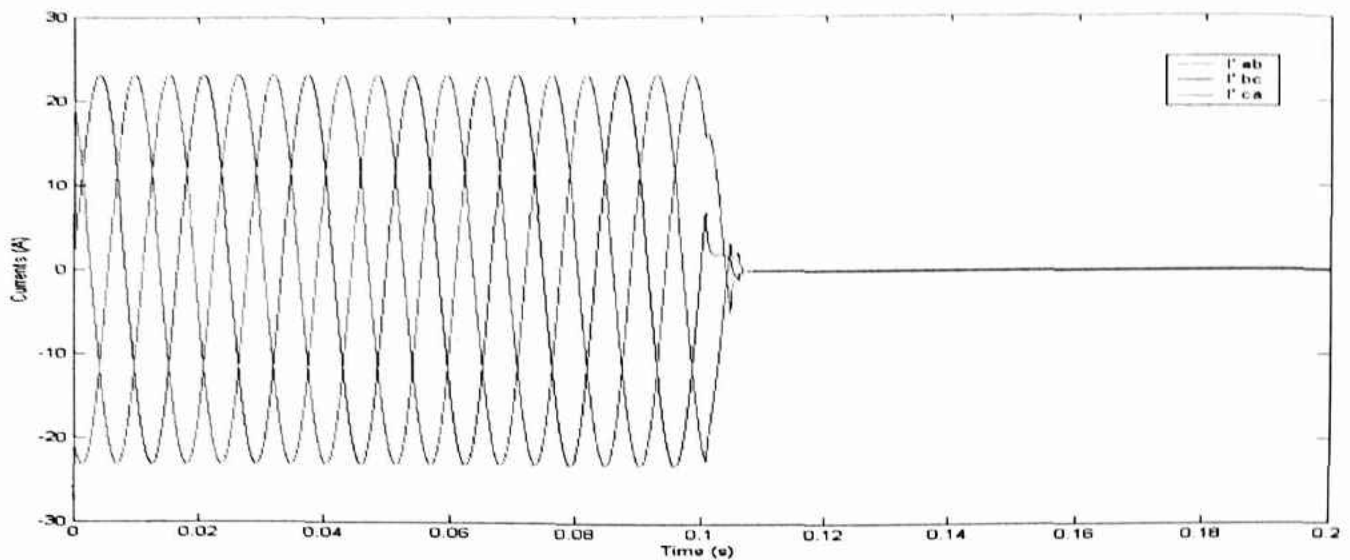
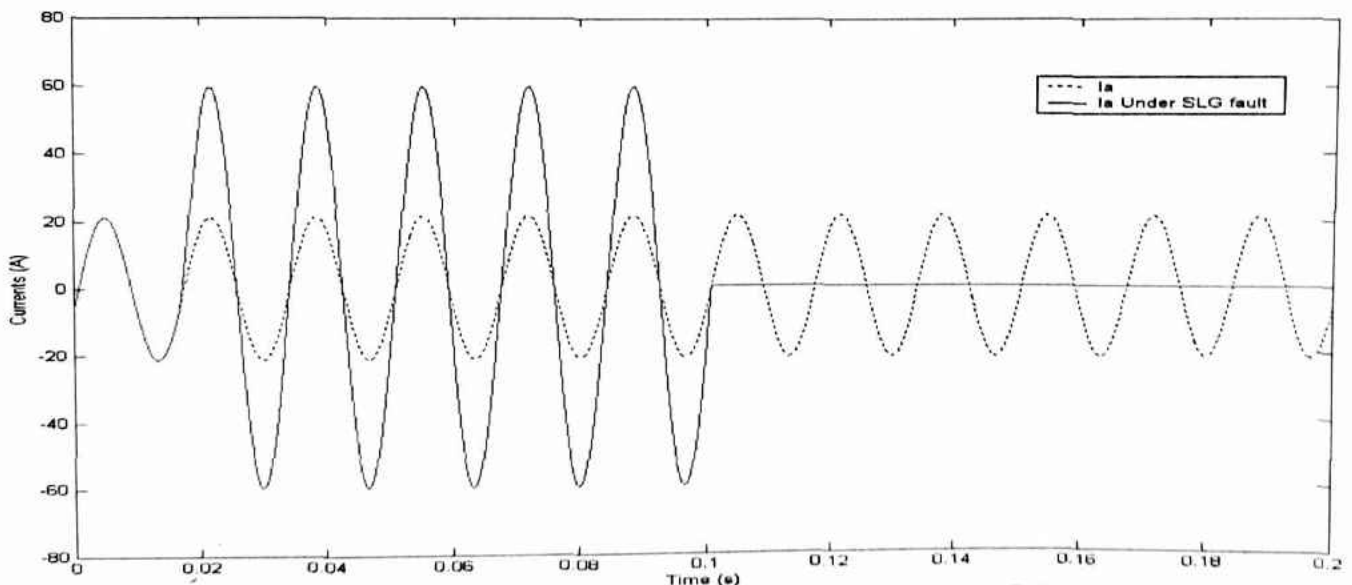


Fig.11: Case 2- Transformer Secondary Currents Under SLG Fault (Line a to ground)

Fig. 12: Case 2- Line Current I_{ac} Under Normal Operation and SLG Fault.

5 Conclusion

NSPS configurations are modeled and simulated using Powerlib/simulink of Matlab. Two test cases were analyzed using a modeled components of Nigeria Naval shipboard power components. Matlab/simulink provides excellent results as observed in simulation figures. However some components parameters needed to be specified

by user in order to fit into the network model. It also has outstanding quality of reconfiguring already modeled components for simulation purposes. Finally, with Matlab/simulink, modeling and simulation of various faults in Shipboard and Utility power system have become interesting and less tedious

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