# Generic Modeling and Analysis Framework for Shipboard System Design

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***Abstract*—This paper proposes a novel modeling and simulation environment for ship design based on the principles of Model Integrated Computing (MIC). The proposed approach facilitates the design and analysis of shipboard power systems and similar systems that integrate components from different fields of expertise. The conventional simulation platforms such as Matlab®, Simulink®, PSCAD®and VTB®require the designers to have explicit knowledge of the syntactic and semantic information of the desired domain within the tools. This constraint, however, severely slows down the design and analysis process, and causes cross-domain or cross-platform operations remain error prone and expensive. Our approach focuses on the development of a modeling environment that provides generic support for a variety of application across different domains by capturing modeling concepts, composition principles and operation constraints. For the preliminary demonstration of the modeling concept, in this paper we limit the scope of design to cross-platform implementations of the proposed environment by developing an application model of a simplified shipboard power system and using Matlab engine and VTB solver separately to evaluate the performance with different respects. In the case studies a fault scenario is prespecified and tested on the system model. The corresponding time domain bus voltage magnitude and angle profiles are generated via invoking external solver, displayed to users and then saved for future analysis.**

***Index Terms*—Model Integrated Computing; Generic Modeling Environment; Shipboard Power System Design; Cross Platform Simulation**

## I. Introduction

Over the last decade, the complexity of ship design has been greatly increased as more and more individual systems and subsystems like weapon system, propulsion machinery, sensors and data acquisition system, power generation and distribution system, are integrated and need to be considered collaboratively during the design phase. Among them, the design of Shipboard Power System (SPS) is of special importance and plays a more and more critical role due to advances in high power-density devices and compact electrical drives. The traditional segregate power system architecture can not satisfy the efficiency and flexibility requirement of the latest All Electrical Ship, and using Integrated power system architecture as the solution is becoming the more preferred choice for modern ship design where a common electrical bus is used to supply power to the loads on demand. The main concern of the power system design is to supply constant power to essential components including propulsion, weaponry, navigation and communication systems. The stability and reliability of the system under different scenarios, especially in the events of battle or damage, is very critical to the mission of SPS design. Careful modeling and simulation to analyze such contingent scenarios is critical for evaluating the survivability of the SPS[1].

Common simulation platforms including Matlab, Matlab Simulink, PSSE, PSCAD, and VTB have been widely used for the simulation and analysis of SPS . These tools provide the utility to model the system on the component level and evaluate performance from different perspectives based on simulation outputs. However, limitations exist for such approach:

- The designers participating in the system modeling and analyzing need to have very explicit knowledge of specific tools in order to develop the application fitting into the desired specifications, and avoid syntactic mistakes, hierarchical component dependencies error or other constraint violations
- Although similar design concepts can still be used across different simulation platforms, it is still relatively time-consuming and expensive to transplant the application model due to the incompatibilities among different tools
- Limited to the variety of tool-specific syntactic rules and constraints, it is hard to be expanded for development of future technologies system updates

Model-integrated concepts has been recently addressed [2] in power systems domain to integrate modeling tools from diverse domains. In this work, a modeling approach based on Model Integrated Computing (MIC) [3],[4],[5] is proposed to support the conventional simulation environment. Objective of this approach is to design a flexible and extensible model-integrated graphical framework that facilitates rapid evaluation of SPS under various testing scenarios across different domains and platforms.

The contribution of this effort are:

1) Seamless vertical integration environment for widely used power systems simulator with focus to particular

SPS environment.
2) Entire design space is represented through characterization and manifestation of shipboard power. systems with domain specific graphical modeling environments.
3) Enables the validation of the SPS design through simulations with realistic application scenarios.
4) Extensible simulator integration framework which supports user specified simulation levels.

The paper is organized as follows: Section II provides a brief review of the software infrastructure of the proposed design. In Section III, two case studies of the proposed approach are elaborated with the analysis of the simulation results. Finally, in Section IV, future work is discussed and the conclusions are drawn.

## II. Model integrated computing and generic modeling environment

### A. Model Integrated Computing (MIC)

The application development and schematic design for power systems has always been a challenge. Stringent time limit, high development and evaluation cost, complex interrelated components and availability are the factors that power engineers cannot solely rely on the physical test bed for system development[6]. Well stated models explicitly capture the structure, characteristics of the target system and the operation environment. On the other hand, models also provide a flexible and efficient approach to perform system design, performance analysis, verification and validation, and artifact synthesis capabilities. MIC approach adopts the model-based paradigm and provides a high-level, abstracted syntax and semantics representation for specifying and reasoning about different design aspects and system properties[3][4]. A modeling language written using the grammar of this high level language can be tailored and be made domain specific[7] and can be made applicable to various control algorithms[8]. Alternatively, it also provides a mechanism for specifying an abstract integration language that can allow the consolidation of common semantics of various commercial analysis tools available for the domain. Then, the challenge remains: how to accelerate the modeling and analysis process? How to precisely capture the critical system specifications? How to extend the design to a variety of applications within different domains?

The concept of MIC is to facilitate the environment designers, by enabling the definition of the syntax and semantic specifications in a way that yields a better overall experience during building and simulating practice of complex applications[7]. For the implementation of MIC, a two level development process is employed[4][6][9]. Software or system engineers operate on the meta-level for specifying and configuring a specific domain; while domain engineers work on the application level to create the application model and analyze the performance. Figure 1 demonstrates the structure of a typical MIC design work-flow.

Meta-level is a domain-independent abstraction that defines a domain specific environment in terms of modeling concepts, component relations, model-composition principles and constraints. In other words, meta-level is the specification of modeling paradigms of system configurations. It contains the base knowledge of rules and constraints of a specific domain and the corresponding representations.

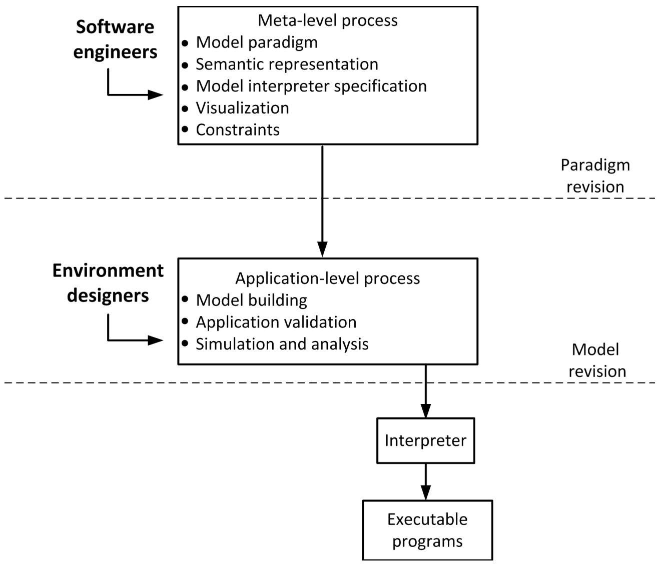


Figure 1. MIC Structure

Application level provides an environment for application model customizations. The objective is to let the environment designers build the model, synthesize executable applications, and analyze the simulation results on the application level. Principles of application operations are based on the semantic representations and paradigms defined in the meta-level. With changes and updates applied to the system, designers can easily modify the model and re-synthesize application files.

A model interpreter is used to convert the knowledge captured in the application models to other useful artifacts[10]. For example, it can be used to generate executable code and configurations files. Upon user's request, attributes and relationships of system components will be acknowledged and synchronized to an executor, which is normally provided by the specific domain. The interpreter will then invoke the executor and generate output in the form of data files, graphs, etc[5].

### B. Generic Modeling Environment (GME)

Developed by the Institute of Software Integrated System at Vanderbilt University, Generic Modeling Environment (GME) is a configurable tool that provides a generic solution for model design and application development for different domain-specific modeling environments[11](figure 2).

A set of generic concepts have been embedded in GME to facilitate the creation of sophisticated systems. Typical modeling concepts of GME include: aspects, attributes, hierarchy, set, reference, and constraints[12][5]. Within a GME project, model, atom, reference, connection and set are classified as first-class objects (FCOs).

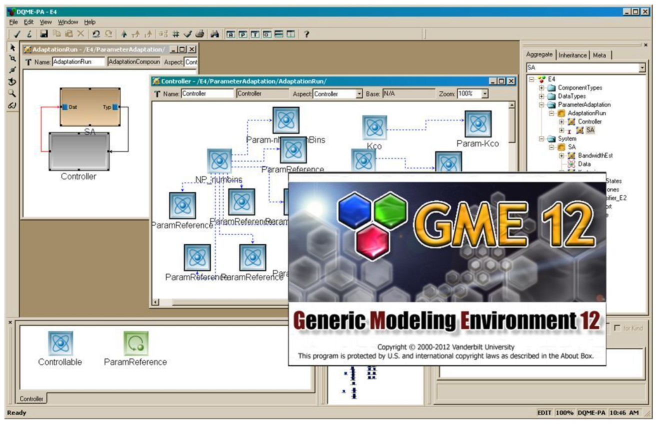

GME 12
Generic Modeling Environment 12
Copyright © 2000-2012 Vanderbilt University
This program is protected by U.S. and international copyright laws as described in the About Box.
Controller
ParamReference
Controllable
Kco
Param-Kco

Figure 2. Generic Modeling Environment (GME)

- *Atoms*: the basic, elementary object, which cannot contain any objects inside
- *Models*: the comprehensive object that can contain other objects and inner structures
- *Hierarchy*: the containment relationships between objects. Every object must have one parent and the parent must be a model
- *Aspects*: the control unit of visibility that determines which part of the model is visible or hidden
- *Connection*: expresses the relationship between objects within the same model. In order to make a connection, the connected objects must be visible to each other, i.e. in the same aspect
- *Reference*: expresses relationships between objects in different system levels or different systems
- *Set*: relationships among a group of objects under the same folder with the same aspect
- *Attributes*: in order to capture information that has no graphical representations, FCOs are affiliated with attributes. The common available attributes are test, integer, double, boolean and enumerated
- *Constraints*: rules made specifically for model-composition and attribute specification.

For a given domain, the paradigm is created as a composition of the modeling concepts as they determine the capacity of a specific application.

Apart from the effectiveness and expandability introduced with MIC, GME also offers a user-friendly graphical design interface. Developing a system model, especially a system with sophisticated components and hierarchical composition like ship-board power system, is an error-prone process. However, instead of the typical, textual representation, GME has offered designers a better option of a more expressive and readable system representation that is visible in the GUI. In this way, the tedious code-based design becomes an easier, more straightforward and more visualized process.[13]

In summary, GME is a comprehensive toolkit that integrates the meta-model editor, meta-model interpreter, application model editor, domain specific codes generator and simulation execution environment.

## III. Case Study

This research work focuses on evaluating and analyzing the static and dynamic performances of a simplified SPS. In order to achieve this goal, toolboxes that are specifically designed for power system analysis and control are carefully studied and chosen. Typical toolboxes like Matpower, Power System Toolbox (PST), Power Analysis Toolbox (PAT), Voltage Stability and Analysis Toolbox (VSAT) and Power System Analysis Toolbox (PSAT) have been widely utilized to perform different power system analysis on a variety of simulation platforms. Common functions supported include the calculation of power flow, continuation power flow, optimal power flow, and small signal stability analysis and time domain simulation.

Matlab engine can be called from the proposed environment to compile the application model parameters into executable Matlab functions and scripts, thereby employing Matlab as the simulation and calculation solver. Through the Microsoft Component Object Model (COM) interface, a library of functions and routines can be called to start Matlab session, transfer data arrays to Matlab solver, send commands, and receive the simulation outputs from the solver. In the framework, Matlab is mainly integrated with other power system analysis and simulation toolboxes to determine the application model performance on a variety of different levels.

One of another targeted simulation platform is VTB developed by South Carolina University[14]. VTB contains an open simulation framework that supports the development of multi-scale and multi-disciplined systems, which makes it ideal for power system analysis. VTB also supports external reuse or repackage utilizing the framework, solvers and components through user-defined interfaces.

In the following case studies, GME will be integrated with Matpower and PSAT which are both toolboxes based on Matlab, and VTB software suite individually to define and create the design environment.

### A. Case study I: Integration with MatPower

For the first case study, Matpower[15], which is primarily used to solve power flow and optimal power flow problems, is integrated with the design environment. The basic procedure for running a simulation in Matpower follows: i),Preparing of the input data matrices that defines all the relevant system parameters; ii), Invoking the main function to perform power flow or optimal power flow calculation, and iii), Displaying the results and saving simulation data in predefined structures and directories.

Modeling of Matpower is based on the standard steady-state power flow analysis models[16]. Equations describing system components and connections are represented in the form of matrices in the Matlab structure. The common fields of the Matlab structure consist of bus, branch, generator and generator costs for optimal power flow analysis. Among them, branches include all the transmission lines, transformers and phase shifters information, and modeled as a standard pi

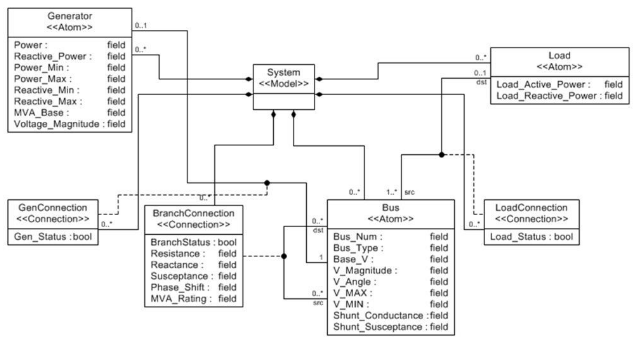


Figure 3. Meta_Model Design

transmission line model with series impedance and charging capacitance. Generators are modeled as complex power injection at a specific bus with an active part and a reactive part, and loads are modeled constant consumption of active and reactive power at a bus. After the specifications of the Matpower *struct* or *case* file, commands like *runpf* and *runopf* are invoked to execute the analysis. The solver of Matpower is relying on the Matlab extension (MEX) files.

1) *Step.1 Create the meta-model:* Based on the Matpower format requirement, the main components in the system can be summarized into Generators, Buses and Loads (see figure 3). Generator blocks contain most of the attributes for the *gen* matrices in the MatPower data file, the Bus blocks contain most of the attributes for the *bus* matrices, and the Load blocks contain the active and reactive power data for the *bus* matrices. There are also three types of connections in the system, branch connections, generator connections, and load connections. The Branch Connection contains data for the *branch* matrices including the destination and source bus of the connection. The Generator Connection includes data for which bus a generator is connected to, along with the generator status for the *gen* matrices. The Load Connection includes the information about the bus number a certain load is connected to and a status attribute indicating the connection status. Once all the components and attributes are settled in the meta model, the next step is to create the application model and code the interpreter.

2) *Step.2 Create the application model:* The application model is created to mimic the medium voltage AC baseline models of shipboard power system developed by the Electric Ship Research and Development (ESRDC)[17]. The fundamental topology includes four turbo-generators connected to a ring-bus which supplies two propulsion motors and four zonal loads. Other components like energy storage system or high-level pulsed load are not included for the simplicity. The main focus on the application model design is to evaluate the static state optimal power flow within the system, thus the control units and dynamic components within the system are also removed. The demonstration of application model is as shown in figure 4.

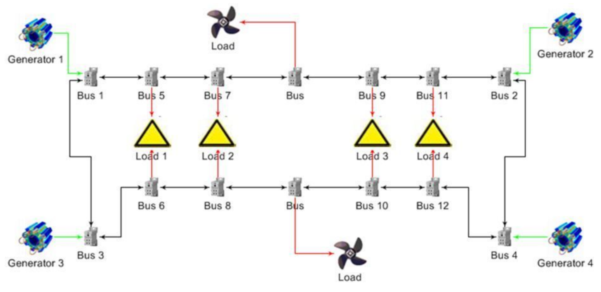


Figure 4. Application_Model Design

3) *Step.3 Interpreter design:* To develop the interpreter, the very first procedure is to collect data from the design interface, and save them in the correct locations. The next step is to ensure that all the constraints are satisfied. The final process in the interpreter is to create the needed m-file and running the Matlab engine to use the files to get the results back. The interpreter is programmed in Visual C++ environment. It uses a dynamically allocated two-dimensional array to save the data. Sample code below shows a section of codes that collects *Bus* data entities from the application model.*getAttribute()* is one of the main functions used to collect attributes of particular names from the system.

```
// Bus_Data_Collection
 ...
if((∗ it )−>getObjectMeta().name() == ”Bus”){
bus_array [0][ buses]=
(∗ it )−>getAttribute(”Bus_Num”)−>getIntegerValue();
bus_array [1][ buses]=
(∗ it )−>getAttribute(”Bus_Type”)−>getIntegerValue();
bus_array [4][ buses]=
(∗ it )−>getAttribute(”Shunt_Conductance”)−>getRealValue();
 ...
}
```

4) *Step.4 Define constraints within the interpreter:* The constraints as shown in the sample script below are described and implemented from a list of constraints decided by the users. Many of constraints are checked using a set of flags and counters during the actual gathering of data. Other constraints, such as the unique bus number, are checked using multiple *for* loops and checking the values from the data collected earlier. If any of the constraints is true, indicating a constraints violation; an error flag is set true and the flag will prevent the file generation as well as the Matlab engine from running. In addition, when there is an error on building the model, an error message will be shown on the console of GME describing the error for the user. If no error has occurred, the interpreter will continue with the file generation.

```
// Generator_Connection_Check
 ...
if(gen_conn_check < total_gens){
error = true;
Console::Out::WriteLine(”Error: Generator(s) not Connected.”);
}
else if(gen_conn_check > total_gens){
error = true;
Console::Out::
WriteLine(”Error: Multiple connections from a single Generator.”);
}
```

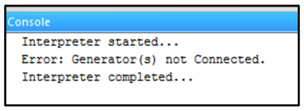

```
Console
Interpreter started...
Error: Generator(s) not Connected.
Interpreter completed...
```

Figure 5. Demonstration of Error Messages in the Console

The following constraints are implemented in the interpreter to ensure the model is created correctly:

- The total available generation power should be greater or equal to the total power demand
- Every Load can only be supplied from *port* bus or *starboard* bus
- Each Bus in the system must have a unique Bus_Num attribute
- Each Generator should be connected to the bus at one and only one spot
- To ensure the continuity of the power flow only one branch can be switched off at one time
- Bus voltage magnitude should be within V_Max and V_Min
- Generator active power and reactive power supply should be within their own limits

If any of these constraints is broken, one of the error messages from Figure 5 will show up in the GME console.

5) *Step.5 Synthesis of configuration information:* Sample script below shows the generated m-file. Once the constraints are all satisfied, loops need to be created to traverse through the arrays to print out the data in the correct locations. The Interpreter also creates the command file to run the case file. The bus data figures and the branch data figures are saved in a file for futher examination. Once the data file is ready, the interpreter will invoke the Matlab engine.

```
// Configuration_File_Synthesis
...
fprintf ( matlab_file , "function mpc = case_1");
fprintf ( matlab_file , "mpc.version = '2'");
fprintf ( matlab_file , "mpc.baseMVA = 10");
fprintf ( matlab_file , "mpc.bus = [ \n");
//Print_Bus_Array
for(counter1 = 0;counter1 < total_buses;counter1++){
 for(counter2 = 0;counter2 < 11;counter2++){
  if(counter2 == 6)
   fprintf ( matlab_file ,"\t1");
  if(counter2 == 9)
   fprintf ( matlab_file ,"\t1");
   fprintf ( matlab_file ,"\t%.2f",bus_array[counter2][counter1]);
    }
fprintf ( matlab_file ,";\n");
  }
...
```

6) *Step.6 Invoke Matpower solver to execute the generated models:* Matlab engine contains a series of API functions which supports C/C++, Fortran among many[18]. These functions are used to invoke Matlab engine and execute Matlab scripts directly within the other programming environments. Data (variables, arrays, matrices, etc.) can be transferred between the C++ workspace and Matlab workspace bidirectionally. Designers can directly call Matlab functions in C++ instead of coding the complicated functions by hand.

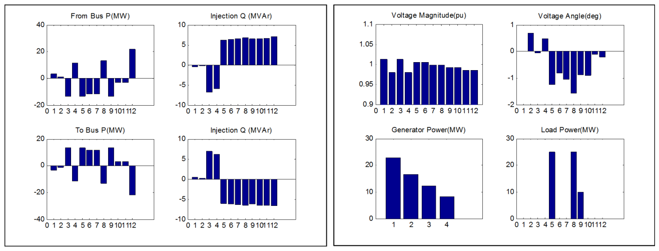


Figure 6. Optimal Power Flow Results

```
//Invode_Matlab_Engine_and_Solve
...
Engine *ep; // define Matlab engine pointer.
char MatlabPath[100]; // current Matlab Path
char p[6000]; //Matlab return buffer
int n=6000;//Matlab return buffer size
ep=engOpen(NULL);
engOutputBuffer(ep, p, n); //push the Matlab output into the buffer
TCHAR NPath[MAX_PATH];//current C++ project path
GetCurrentDirectory(MAX_PATH, NPath);
strcpy(MatlabPath,"cd ");
strcat(MatlabPath, NPath);
engEvalString(ep,MatlabPath); //change the Matlab project path to the C++ path
engEvalString(ep,"Matpower");//execute the m-file
Console::Out::WriteLine(p);
...
```

7) *Step.7 Display of the simulation results:* The simulation results are presented in figure 6.

The purpose of integration with MatPower case study is to provide a tangible approach demonstrating the utility of the proposed environment. However, Matpower has its own limitations. In the second case study, we integrate PSAT with more functionality including dynamics and larger component libraries.

## B. *Case study II: Integration with PSAT*

This case study exploits the potential of the proposed generic modeling concept through well tested open source tool PSAT[19]. Static and dynamic analysis algorithms defined within PSAT supports the corresponding models including power flow data, switches, loads, measurements, loads, machines, controls, FACTS, and user defined models[20]. PSAT provides graphical user interface (GUI) with a customizable Simulink-based library to assist the system design, in addition to command line interface. In this case, PSAT is explored through the command line interface rather than existing GUI to access the global structure, modify component parameters, set desired options, and directly invoke PSAT engine to execute configuration files. For the second case study, our main purpose is to expand the design environment to another domain specific toolkit with similar data structures and specification formats. It suggests that the interpreter design, data collection procedure, constraints settings, and configuration synthesis process will be of very close patterns from the previous design in case study two. Thus, the meta-model creation and the application design are the emphasis with the demonstration of more functionality, more designer interface flexibility, and more detailed results analysis capabilities.

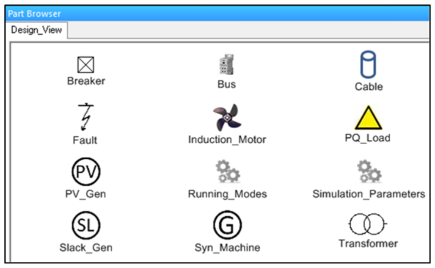
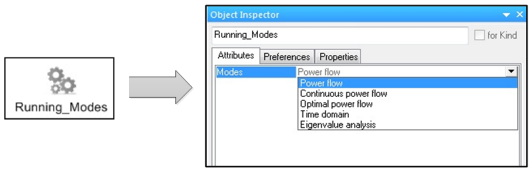


Figure 7. Entities Library Generated From Meta-Model

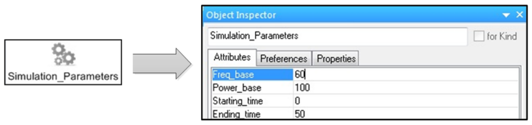


Running_Modes

Modes: Power flow

- Power flow
- Continuous power flow
- Optimal power flow
- Time domain
- Eigenvalue analysis

Figure 8. Running_Mode Settings



Simulation_Parameters

| | |
|---|---|
| Freq_base | 60 |
| Power_base | 100 |
| Starting_time | 0 |
| Ending_time | 50 |

Figure 9. Simulation_Parameter Settings

*1) Create the Meta-Model:* The set of rules for meta-model development follows the similar concept as defined for the first case study. However, the inclusion of the system dynamics in PSAT requires more information to reflect the system characteristics. Thus the meta-model needs to be extended with more entities and more detailed parameter specifications. Every power system analysis tool can have their unique data requirements based on the unique design philosophy. While the basic information requirement from power system modeling remains same, upgrading the system utilizing particular tool operations or adding different functionalities is a common scenario for meta-model update.

Interactions between generators, transmission line, load and associated controls, as well as those components themselves, are supplemented through meta-model . Generators are abstracted by fourth order model and IEEE type 1 automatic voltage regulator (AVR). Load models are described in rich details including constant power, ZIP, and exponential recovery in the meta-model. As testing the vulnerability of SPS with various fault scenarios could greatly strengthen the stability and survivability, this concept is captured in meta-model as fault atoms with various parameters including fault interval, resistance and reactance magnitude. Breakers are made available with switching intervals to trip the faulted buses. Transformer, cable, bus, and other components remain same as defined in first case study. Thus generated library from the meta-model for this case is shown in figure III-B2. The Running_modes setting in the library, as shown in figure 8, allows application model designer to specify one of the operations among power flow, continuous power flow, time domain and small signal stability analysis (eigenvalue analysis). Main settings of the system simulation such as frequency, power base ratings, starting and finishing times, can also be modified by designers at any time through the Simulation_parameter setting.

*2) Create the Application Model:* Application model remains almost same across different tools; however, inclusion of different features can encourage application developer to add corresponding functionalities based on the needs. The application model as shown in figure 10 is similar to the SPS model presented in Case Study I but, dynamics associated analysis and evaluations can be accessed by the environment designers in this case.

*3) Verification of Simulation Results:* Time-Domain simulation results of bus voltages changing before and after a three phase fault are presented in Figure 11. The system was in stable steady state operation before the fault is applied at t=16 seconds. However, after the fault, system voltage oscillates and becomes unstable. Reconfiguration action is not taken into account. This is a simple demonstration of a variety of utilities provided in the design interface. Designers can choose different types of analysis to evaluate the comprehensive performance of the application model.

## *C. Case study III: Integration with VTB Suite*

In the proposed framework, VTB is used as an alternative approach to create power system schematics and simulate the real-time performance of the shipboard systems. As an overview, VTB is a suite of simulation tools to virtually prototype of sophisticated and dynamic systems. It provides strong support for systems which contain complex hierarchical structures and a number of cross-disciplinary and non-linear components. VTB facilitates the design and analysis procedure of the by offering flexible interface to external environments or platforms, thus new components, new solvers and new models can be added for further updates through COM and .NET interfaces.

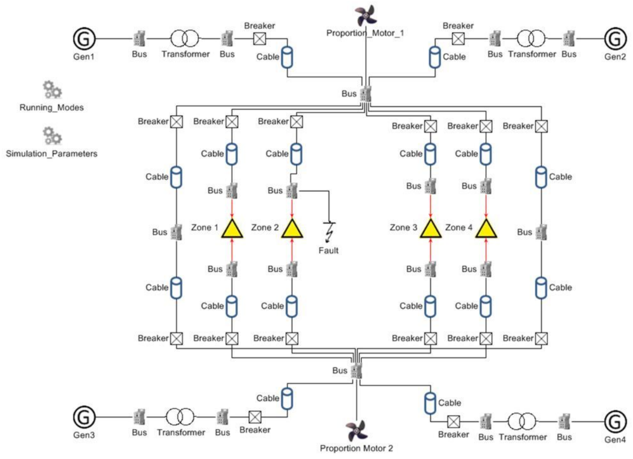


Figure 10. Application Model for Case_2

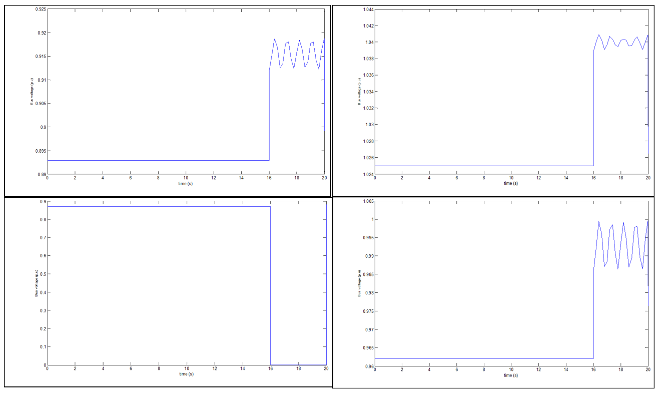


Figure 11. Bus Voltage response to fault

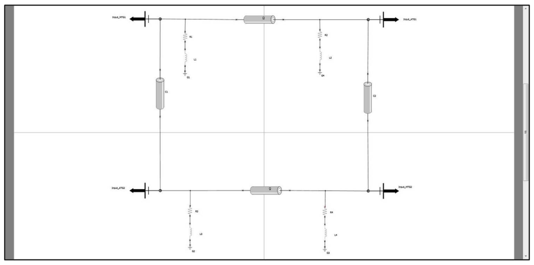


Figure 12. Ring Bus System Topology of the Application

The VTB suite includes three main components such as schematic designer, entity designer, module designer, and four types of solvers including Natural solver, Phasor solver, Signal solver and Quantity solver. In the proposed framework, a generic electric ship system model with integrated power system that is built within the schematic designer is used for the case study. VTB libraries of simulation components are used as well as the natural solver to perform the corresponding real-time analysis. The simulation results generated via Matlab as discussed before and VTB suite are compared to verify the compatibility of the proposed framework.

*1) Description Of the Study System:* The system model for the VTB case study is shown in Figure 12.

As shown in the figure, the system has the basic ring-bus topology, where two 36 MW main generators and two 4 MW auxiliary generators are attached on each corner. Generators are interconnected via cables and RL branches as filters.

Figure 13 demonstrates the detailed internal system of the two main synchronized generators in VTB.

As observed in Figure 14, each of the main generators contains one synchronous machine, one gear box, one gas turbine, the excitation system and an automatic synchronizer that controls the operation status of the generator. Auxiliary generators within the system have the same composition with different parameters, thus this structure is chosen as the default representation of generators in the proposed framework.

*2) Creation of Meta-Model and Application Model:* In accordance of the topology of the application model, we can create the meta model as shown in Figure 15. The paradigm

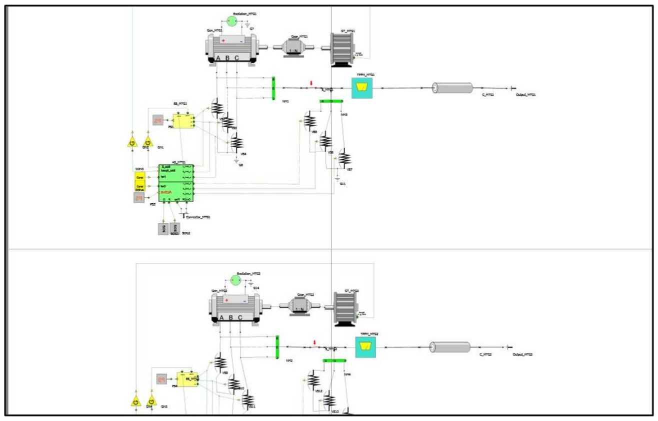


Figure 13. Structure of The Two 36 MW Main Synchronized Generators

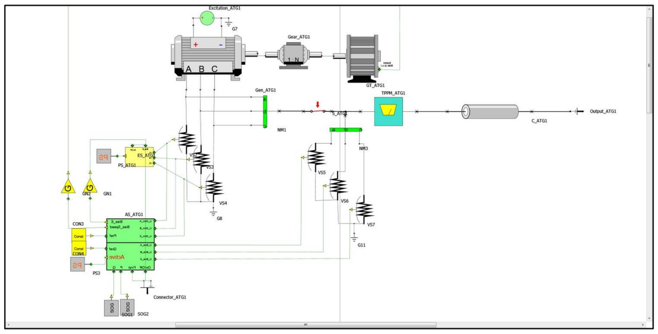


Figure 14. Detailed Components View Within the Main Generator

includes five types of components, Generators, Loads, Induction motors, Cables and Breakers. Among them, Breakers are used to control the triggering time of each generator. In addition to that, the Plotting_option let users choose from a drop-down menu the desired simulation output to view, and Simulation_Parameters defines the necessary simulation parameters including end time and simulation step time.

Based on the VTB application system and the created meta-model, the system model can be represented as shows in Figure

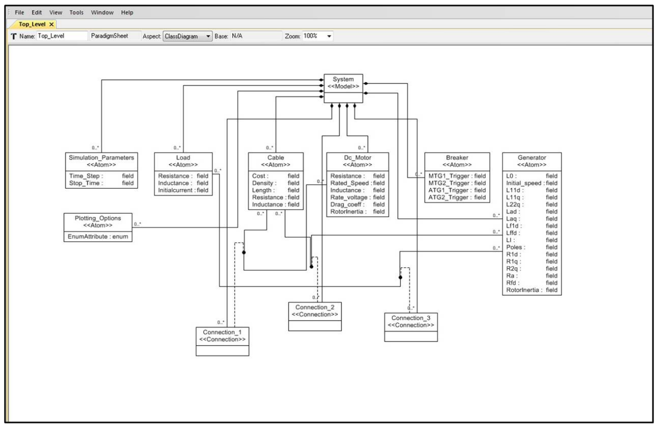


Figure 15. Meta-Model of The Generic Ship Power System In VTB

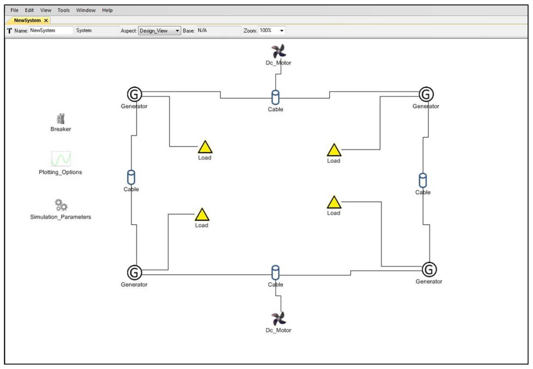
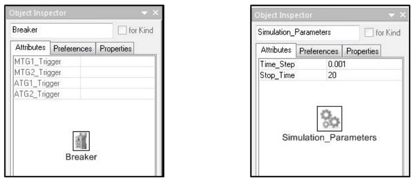


Figure 16. Application Model of The Generic Ship Power System In VTB



```
MTG1_Trigger
MTG2_Trigger
ATG1_Trigger
ATG2_Trigger
```

```
Time_Step   0.001
Stop_Time   20
```

Figure 17. The Breaker Options and Simulation Parameter Definitions

16. Generator sets are connected to the network via cables. Zonal loads and induction motors are attached in accordance to the actual application model.

Figure 17 demonstrate the detailed options and attributes of objects including Breaker and Simulation_Parameters.

*3) Design of the Interpreter:* The interpreter works in a similar way as in the case study with Matlab integration. Information including the device types, number of each components, interconnections and parameters are gathered from GME interface first, and then classified and reorganized in the format required by the VTB engine to perform the simulation. Assembling a VTB based system includes the following steps:

- Created the a blank system and add components into the system via using their unique TypeID

```
IVTB oVTB = new VTB.COMInterop.VTB();
IVTBSystem oSystem = oVTB.CreateVTBSystem("TestSystem");
IVTBSubsystem oSubsystem =
        oSystem.CreateVTBSubsystem("Electrical_Subsystem");
IVTBComponent oResistor1 =
        oSubsystem.AddVTBComponent(g_gResistorTypeId.ToString(),
        g_sDefaultComplexity,"R1");
```

- Add the ports of each components with connections and build the connection topology

```
IVTBPort oESPort1 = oES1.GetVTBPort("VA");
IVTBPort oESPort2 = oES1.GetVTBPort("VB");
IVTBPort oESPort3 = oES1.GetVTBPort("VC");
oSubsystem.Connect(oESlport1, oESPort2);
```

- Define parameters of each component

```
IVTBParameter oInitialSpeed1 =
        oSynchMachine1.GetVTBParameter("InitialSpeed");
IVTBParameter oL01 = oSynchMachine1.GetVTBParameter("L0");
IVTBParameter oL11d1 = oSynchMachine1.GetVTBParameter("L11d");
```

- Define the simulation configurations and start the simulation

```
oVTB.SetStopTime(10.0);
oVTB.SetTimeStep(.001);
oVTB.Start();
```

- Record the outputs in the destination text file

```
oVTB.SetOutputFile( g_sInstallationLocation  + "//MyResults.txt");
oVTB.RecordVTBViewable("Electrical_Subsystem.SM1.StatorVoltageA");
```

- Import and plot the outputs in the schematic designer

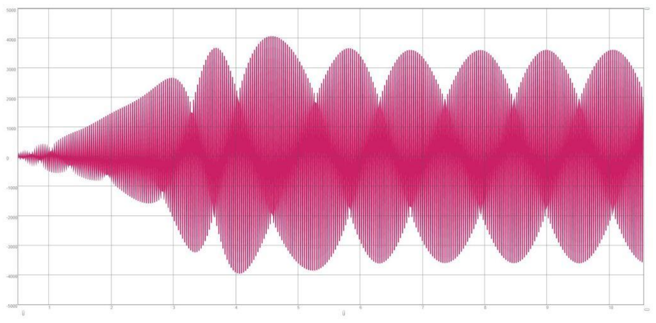


Figure 18. Phase A of The Stator Voltage in Main Generator 1

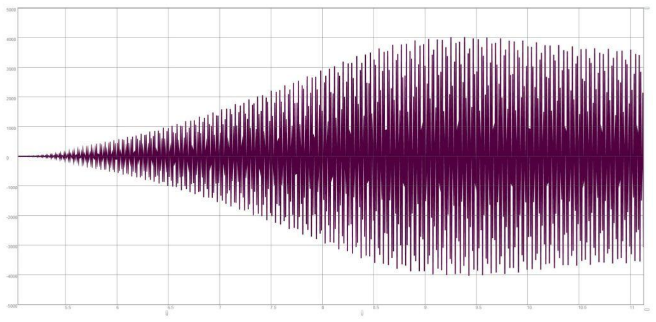


Figure 19. Phase A of The Stator Voltage in Main Generator 2

The plot of simulation results is shown in Figure 18 and Figure 19.

## IV. Extensibility

Extensibility adheres with the main design principles behind GeMSES. Third party users are able to add the features on the existing simulators or integrate new simulators with ease. To implement the integration, general approach is to first integrate the updates with the current paradigms on the meta-model level. Users are then required to add corresponding sections within the interpreter to work with new simulator. Standard integration requires all the necessary information to describe certain application with the particular simulator for current paradigms. Application model will not be compatible with the design environment with any insufficient piece of information.

*Model migration* has some challenges in model computing framework due to the necessity to confirm to the new modeling paradigm for translation. Interpreter porting is another challenge apart from model translation. Interpreter needs to be updated upon the corresponding change in the paradigm. However, Interpreter remains intact with new modeling concepts.

## V. Conclusion and Future work

In this paper, the concept of Model Integrated Computing is presented to integrate with different power system solutions, in order to support the development and analysis of shipboard power system and other similar systems. GME toolkit is utilized to develop the meta-model and application model. Currently, Matpower, PSAT toolbox and VTB are supported by the proposed environment for synthesizing applications and performing various kinds of system analysis. In future, the current design will be updated and expanded to other computational platforms to exploit the full potential of the model-based approach.

Even, simulation scenarios and control algorithm needs to be tested in real time before it gets deployed for application. Dedicated power system simulation platform such as RTDS, with the ability to integrate with hardware is another potential extention to this work. RTDS is one of such platform that allows real time applications testing and faster simulations along with other benefits. The integration of RTDS to the present environment would further prove the extendibility and practicability of the proposed integrated modeling approach. [10]

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