Benefits and Techniques of Integrating Embedded Training Capabilities in Legacy Hardware-Specific Control Systems

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ABSTRACT

The benefits of embedding training capabilities as part of the physical equipment used during tactical operations are well known and widely accepted in the U.S. military training communities. Embedded Training (ET) provides a realistic and effective training experience that is identical to live operation and, since the training is conducted in the operational environment. The benefits of ET are most obvious when implemented on systems with unique Human System Interfaces (HSI) that consist of hardware buttons, levers, multiple indicator types and different display technologies. The focus of this paper is to describe the benefits and techniques of integrating Embedded Training capabilities into a shipboard control system and to provide practical insights into the integration process. The process will be illustrated using the implementation of ET for a control system of an electric generation plant aboard a U.S. Navy destroyer.

Integrating ET features in an existing (legacy) hardware and software system presents several technical challenges that require innovative techniques to accomplish the design objectives. Creating an effective instructor interface, addressing multiple software languages, handling data conversions, dynamically rerouting hardwired signals, and providing real-time hardware-in-the-loop simulation models that mimic mechanical, and electrical components are a few examples. The ET system consists of an instructor workstation with a Graphical User Interface (GUI) that allows the instructor to control the real-time dynamic simulation of the plant equipment. The instructor workstation connects to the physical control system equipment and allows the instructor to perturb the signals coming to the equipment for creation of various training scenarios. The simulation model provides excitation to the control system equipment as if the signals were coming from the real plant giving the operator an exact replication of live operation. Through the description of this ET system, the authors intend to present information that may be applied to other embedded training programs.

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INTRODUCTION

The Navy currently uses a combination of training methods to obtain and maintain operational proficiency for the Machinery Control System (MCS) personnel: operational training at Surface Warfare Officers' School (SWOS), hot plant and maintenance training at land-based engineering facilities and limited shipboard training (On the Job Training (OJT)). Operational training consists of a combination of class room training, simulator training and training on actual equipment assembled to replicate the ship's environment. These training operations are well established and provide an excellent foundation.

Shipboard training is essential for maintaining operational skills and for improving proficiency. It currently consists of running training drills on the control consoles while operating the actual plant. This method of training has several limitations and does not provide realistic or efficient training. For example, there is currently a limited capability to simulate casualties for practicing casualty response procedures. In many cases, the casualty must be imagined or simulated by placing a paper representation of the indication over the actual indicator. Likewise, the trainee is often prevented from performing the correct action and must imagine the expected response to any actions. In addition, any incorrect actions by the trainee may be hazardous to personnel and could cause damage to the equipment.

Embedded Training (ET) is intended to provide realistic shipboard training under conditions that are as similar as possible to the real world without operating or interfering with the continued operation of the ship's equipment. It is available while pier-side or underway. The difficulty in providing this capability on the legacy architecture, such as the DDG Machinery Control System (MCS), is the hardwired connection of console indicators, buttons and switches directly to the ship's equipment, i.e. hardwired signals. To maintain these hardwired controls and provide realistic embedded training, hardwired signals must be temporarily disconnected and redirected to a real-time simulation of the ship's equipment. In this manner, the console can support embedded training for the associated system control functions, operating just like the system performs during normal operation.

The Embedded Training System (ETS) monitors critical MCS parameters while in training mode and provides for entering and exiting training mode safely. The ETS provides for individual training (single console) and discrete team training (multiple consoles) and enables future capabilities to support integrated team (ship-wide) and Battle Force (fleet-wide) training. The ETS supports normal plant operations and casualty response training as defined by the Navy's existing procedures. The training instructor is able to monitor the operator's actions and control the plant simulation. He can insert casualties manually or execute predefined sequences of timed casualties. The ETS enables future enhancements for automated training scenarios, where the instructor is able to select and initiate pre-defined drill sets with automated system responses to operator actions. Events will be automatically captured and the instructor will be able to monitor, review and evaluate operator actions. Additionally, ETS will enable future changes for automatically making the captured events available for review; and for providing automated performance assessment, record keeping and grading aids. It is designed for future expansion to support training for the entire ship's crew and provide realistic battle damage, stochastic failures, and operator induced failures.

Integrating an embedded training capability into the Navy's legacy systems offers many advantages:

- State of the art training capabilities while leveraging off their investment in existing equipment
- Minimized costs and disruption to ship's availability during refit
- Training in the real environment, on the real console without the expense and risks of operating the real plant equipment
- Support for the Navy's goals of improved training and reduced manning.

DDG MACHINERY CONTROL SYSTEM DESCRIPTION

There are 44 commissioned US Navy Arleigh Burke class ships currently in service. DDG-51 was the first ship ordered in 1985 and commissioned in July 1991. The engineering systems of this ship are controlled by the MCS designed and built by Lockheed Martin Simulation Training and Support (LM STS) located in Orlando Florida. The MCS consists of two Shaft Control Unit (SCU) consoles, Propulsion & Auxiliary Control Console (PACC), Electric Plant Control Console (EPCC), Engineering Officer Of the Watch (EOOW), and Damage Control software running on seven TAC workstations. Figure 1 depicts the MCS connected by the ship's Fiber Optic Data Multiplex System (FODMS).

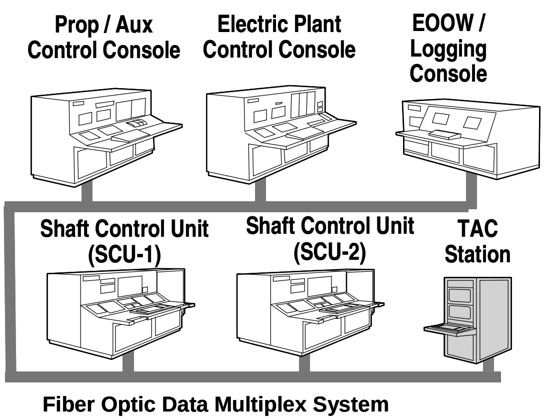

Figure 1 DDG Machinery Control System

The functionality of each MCS console is system specific. The EOOW console is a monitoring and logging console that allows the engineer in charge of the engineering systems to see all parameters controlled and monitored by all MCS consoles. The EOOW data logs all alarms and takes a snapshot of all signals every hour. The PACC allows an operator to control the forward and aft speed of the ship and various auxiliary systems such as seawater cooling pumps and lube oil systems. The PACC controls and monitors the propulsion system via communications with the two SCUs.

Each SCU has control and monitoring signals to and from two main propulsion Gas Turbine engines, a main reduction gear and a controllable reversible pitch propeller. The EPCC controls and monitors the electrical power on the ship by direct controlling of three gas turbine generators and various circuit breakers. The TAC workstations provide an interface to monitor heat, smoke, fire, water, and control firemain pumps and valves for damage control.

Over the last 10 years the MCS has been modified by engineering changes that have brought the current system to a configuration that facilitates the incorporation of ET. The use of Versa Module Europa bus (VME) standard chassis and circuit card assemblies (CCAs) allows for easier software addressing of I/O compared to discrete Standard Electronic Modules (SEM). The conversion of all software from CMS-2 to C greatly improved the ability to modify the software for ET. All of these changes helped modernize the MCS, but did not eliminate the hardwired signals that require redirection from the ship's systems to the simulation. Of all the consoles the EPCC has the largest quantity of direct hardwired I/O with no software intervention.

Focus on the Electric Plant Training

The Navy decided to take an incremental approach to implementing ET on the DDG-51 class ships. The EPCC was chosen as the first console to incorporate and field test ET. The EPCC's high concentration of hardwired signals made the console an ideal candidate for proving out I/O redirection during simulation.

The photograph in Figure 2 illustrates the operator interface of the Electric Plant Control Console.
The large vertical panel allows the operator to monitor the power, current, and frequency and to adjust the voltages and frequencies of the three generators. The panel also has a system power meter and a synchroscope used for synchronizing different sources to the main bus. The panel AMLCD display presents monitoring information via text based alarm, summary group and status screens with colored graphic screens displaying individual systems such as the Remote Independent Mechanical Starting System (RIMSS). The information on this display is provided

via the FODMS the ship's communication network backbone.

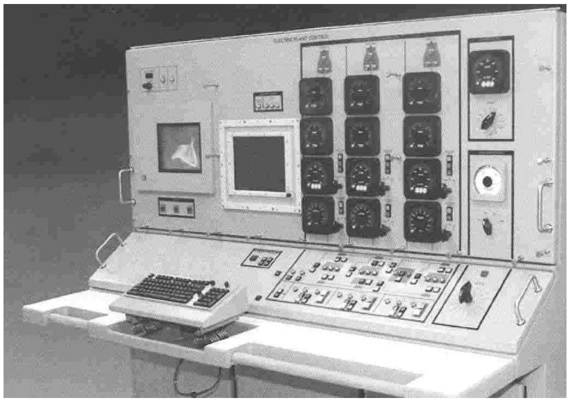

Figure 2 DDG Electric Plant Control Console (EPCC)

The LCD display presents monitoring and control of the three RIMSS used for starting the three gas turbine generators. The information on the LCD is communicated via an RS232 link to controllers on the three generators.

EMBEDDED TRAINING SYSTEM ARCHITECTURE

The embedded training system (ETS) consists of two major components added to the existing MCS as shown in
Figure 3:

- ET hardware components and software modifications added to the machinery control system console
- Training Instructor Workstation Station (TIWS) containing the ET utilities, system simulations and control functions

The MCS ET components provide the functions needed to enable the ETS capabilities and produce realistic responses to the operator actions. The ET hardware and software are integrated such that they have minimal affect on the current operation of the console.
Like many legacy systems, the electric plant control console (EPCC) has several pushbutton switches directly connected to the devices they control and are not monitored by the processor. Similarly, many of the console indicators and meters are hardwired to the status signals that are supplied by the ship's equipment. To enable embedded training, these signals must be disconnected from the ship's equipment and connected directly to the processor.

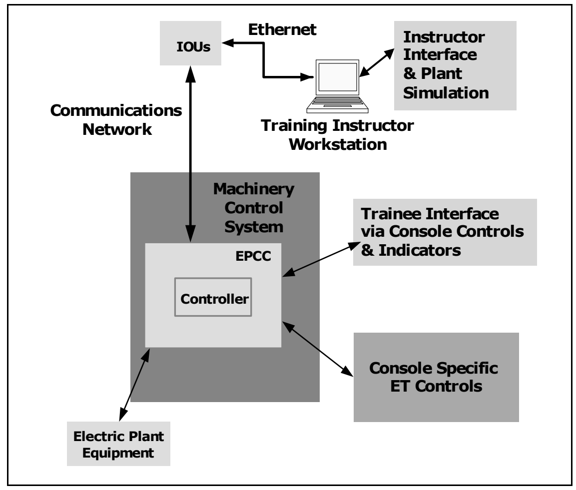

Figure 3 Embedded Training System Architecture

The ET System uses new I/O (input/output) circuit card assemblies (CCA) for the additional ET inputs and outputs in the EPCC. The new CCAs provide front panel cable connections to avoid the need for backplane modifications and simplify installation. A switching assembly added to the EPCC contains the ET switching relays and components to redirect the signals from the hardwired switches and indicators to the control processor during embedded training operation. The switching assembly interfaces with the existing console panel I/O connectors to minimize and simplify hardware modifications. An illuminated pushbutton switch, added to the console, signals the initiation of embedded training for the console, allows the operator to acknowledge instructor requests to enter or exit embedded training and to indicate when the console is in embedded training mode. The EPCC also receives two frequency controlled AC power sources to stimulate the electro-mechanical synchroscope during training. The embedded training system software executes on the existing console processor. The new console software functions enable communications with the TIWS and provide additional controls for the embedded training functions. The new software also monitors critical parameters and transmits them in a new data message to the TIWS.

When the console is in the normal operating mode, the ETS processes are inactive and the ET control hardware is disconnected. The normal hardwired signal connections are maintained. When the ETS processes are enabled, they intercept the console inputs and take control of the outputs. The ET switching assembly disconnects the hardwired signals from the ship's equipment and connects them to the ET processes to be monitored and controlled by the simulation. Control process output signals are blocked from the ship's equipment and redirected to the simulation. Console inputs from the ship's equipment are redirected to the ET software for adverse condition monitoring and the console control processes receive inputs from the simulation running on the TIWS. The internal messages created from existing CCAs are intercepted and modified depending on the training mode selected.

The TIWS provides the simulation/stimulation functions, the ability to select and execute training procedures, and utilities to monitor and control the plant simulation. It also enables the instructor to coordinate discrete team training and to monitor training results. The system simulation in the TIWS responds to the control signals from the console and provides realistic, dynamic responses to the console to imitate the real equipment. It also responds to various control inputs to allow the training instructor to alter the operation, condition and alignment of the plant simulation.

The TIWS connects to an IOU (input/output unit) and communicates with the console via the ship's existing network using newly defined parameters contained in the existing console status change message and new TIWS and console data messages.

SYSTEM DESIGN

Requirements Analysis

Requirements analysis and development took a conventional approach. Documentation of the existing system and relevant customer information was obtained to assess the current state of the system and training methods employed. The Navy's training mission requirements and future goals, like modernization and reduced manning were investigated and integrated into the embedded training system design goals and high level requirements. The results of these investigations and analysis were captured in two documents. The Concept of Operations document describes the operational environment, how to use the system and provides a general understanding of the proposed system from the user's perspective. The Technical Description document details the system functional and physical architectures, defines top level functionality and specifies some of the hardware and software design requirements and constraints.

Once the customer's needs and system goals were documented, sufficient trade studies completed and risk and cost assessments completed; a system/segment requirements specification (SSRS) was generated. The SSRS provides a definition of the system requirements that is concise, consistent, complete and testable. The SSRS underwent a series of peer reviews, customer reviews and revisions until all requirements were understood and acceptable to all stakeholders.

After the system level requirements were approved, they were handed to the software and hardware development teams to derive the software and hardware design requirements. These requirements were then used to guide the system development implementation as well as to provide a basis for the system integration and test efforts.

Engineering Operating Sequencing System (EOSS) Training Session

The EOSS is the Navy's system used for training sailors on the equipment they operate and the watches they perform. The EOSS is tailored for each ship and delivered on electronic media. The ship uses paper notebooks at each watch station containing only the procedures specific to that station. The ET system includes the capability to exercise the drills defined in the EOSS to provide effective operator training on targeted equipment and watch standing.

The EOSS encompasses both Engineering Operational Procedures (EOP) and Engineering Operating Casualty Control (EOCC) procedures. These procedures support Engineering Officer of the Watch (EOOW), Propulsion, Electric Plant, Fuel fill & Transfer, and DC/Firemain operations training.

The EOP provides procedures for normal operations with Master Plant Procedures (MPP) giving the overall procedure based on commands from the EOOW or Officer Of the Deck (OOD). Component Procedures (CP) are comprised of detailed procedures for specific operations to support the overall operation of the training session.

The EOCC consists of Master Casualty Response Procedures (MCRP) that overview a specific casualty with Casualty Response Procedures (CRP) giving specific direction for the watch area to respond to that specific casualty. The EOCC also consists of Master Emergency Procedures (MEP) for use by the EOOW and Emergency Procedures (EP) that cover procedures when there are several casualties or hazardous circumstances.

An example of an MCRP is Master Bravo Gas Generator Module (MBGGM) a Class B fire in Gas Turbine Generator Module. This procedure provides an overview with possible causes, possible effects, and controlling actions to be orchestrated by the EOOW. The CRP BGGM for a Class B fire in Gas Turbine Generator Module provides procedures for immediate actions to be taken by the watch standers at the EPCC and engineering spaces.

A training session using the BGGM entails a training instructor setting up the TIWS laptop by connecting it to a FODMS node. This allows the instructor to either be in view by the operator or obscured. The instructor starts the TIWS application then selects the Hull number of the ship to have the proper configuration. The instructor initiates a training session by selecting either signal insertion mode or simulation mode. When the mode is selected the TIWS sends a command to the EPCC to enter ET. The EPCC determines if all of the safeties are in place, such as switchboard in local control. If the safeties are met the console starts flashing the Training Mode Select pushbutton on the front of the EPCC. The operator then presses the button to acknowledge the start of training. The button illuminates steady and the EPCC software switches to simulation mode. The instructor then sets up the initial conditions of the simulated plant to perform the BGGM casualty procedure. The instructor uses the EPCC GUI to start two Gas Turbine Generators, bring them onto the bus, and close the appropriate circuit breakers so the generators are loaded. The instructor aligns the third generator to a standby state. The instructor initiates the casualty by setting one of the two flame detector signals in the SIS dialog or the CIS dialog. The EPCC operator will observe one of the following:

1. "GTG ___ MODULE FIRE" alarm displayed on Plasma Display.
2. "GTG ___ MODULE TEMP HIGH" alarm displayed on Plasma Display (250 F).

The EPCC operator should follow the BGGM EOSS procedure to open the affected generators circuit breaker, command the release of primary halon, start the standby generator and monitor the affected generator module temp. If ordered by the EOOW the operator should activate Primary and perhaps Reserve Halon to extinguish the module fire. After completion of the casualty the instructor can initiate a related casualty such as a Generator High Inlet Temp (GHIT) procedure or initialize the simulation for the next training session.

PLANT SIMULATION MODELING

The plant simulation provides the simulation/stimulation and switching functions needed to enable Embedded Training and produce realistic responses to the trainee actions. This requirement imposes a rather stringent accuracy requirement on the physical models of the plant. The approach taken here is to develop physical relationships among various components and subsystems of the plant and integrate them into a large simulation model.

The lumped-parameter modeling approach is a standard practice in control system design and analysis in which system dynamics are described in terms of ordinary differential equations (transfer functions). Figure 4 illustrates a simple model of a gas turbine fuel metering valve in block diagram form. The percent valve stroke is the input to this model and the output is the mass fuel flow out of the valve in pounds per hour. The lookup table is a nonlinear relationship between percent stroke and the amount of fuel flow out of the valve. The Fuel Valve Dynamics block is a transfer function describing the dynamic behavior of the valve.

For small-signal studies, linearized representations of system characteristics are often adequate. For large transient or disturbance studies, the models will include all significant non-linearity's, such as saturation and limiting. Non-linearity can be approximated in one of two ways; by linear approximation and empirical data sets or look up tables. The simulation models for the DDG Embedded Training system include both linear and nonlinear elements as shown in the Figure 4 example.

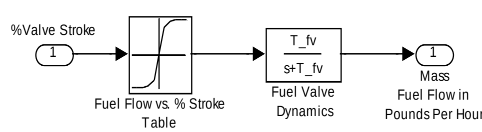

Figure 4 Dynamic Model of a Turbine Fuel Valve

Matlab/Simulink has been selected as the modeling tool for developing the simulation models of the DDG plant equipment. Figure 5 illustrates the three basic steps in developing the simulation models

1. Model the physical ship systems using the Matlab/Simulink software. The tool allows the models to be described in block diagram form.
2. Analyze the model within the Matlab environment to make sure the model characteristics are real and comparable to actual ship data provided by the Navy.
3. Utilize the Matlab tool to automatically generate real-time C code from the model block diagrams.

The generated C code is then integrated with various software modules and executed on the Training Instructor Work Station.

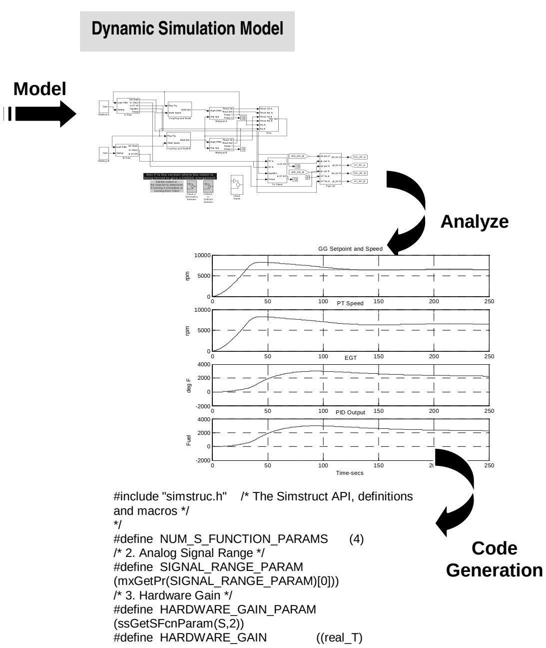

Figure 5 Plant Simulation Development process

The plant simulation of the DDG electric plant consists of several detailed mathematical and logical descriptions of the three turbine generators, the electrical distribution components, and various supporting subsystems. A relative measurement of the magnitude of the DDG plant simulation is the number of software lines of code (SLOC) that has been generated from the Matlab simulation models. At the time of the writing of this paper, the SLOC count for the electric plant simulation has reached close to 40K SLOCs.

INSTRUCTOR WORKSTATION GUI DESIGN

The user interface for the TIWS deviates from conventional user interfaces in two ways; one is the combination of text based and graphics allowing the instructor to both monitor and interact with the simulation or console and the other is the use of modeless dialogs.

Graphics which mimic the front of the EPCC console are presented from the EPCC tab on the main application window. The EPCC mimic allows the instructor to monitor the console and to interact with the simulation. Specific EPCC subsystem graphics are also available from the EPCC tab that allows the instructor to monitor the various EP subsystems such as the Electric Plant, the three gas turbines and RIMSS systems.

Modeless dialogs are different from conventional dialogs in that they allow the user to interact with the main application window while the dialog is visible. For example the instructor may interact with signals being input into the simulation and signals output to the console at the same time. Modeless dialogs may be minimized or maximized as needed.

The EPCC tab is shown in Figure 6 with the Simulation Input Signal and Forcible Output Parameter modeless dialogs. The graphic shown is the EPCC mimic representing the actual EPCC console functionality.

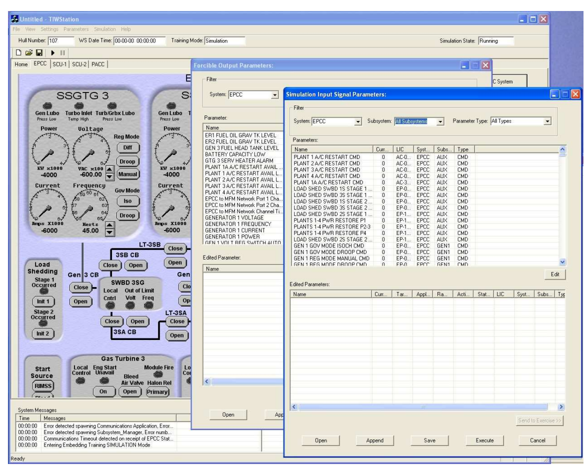

Figure 6 TIWS Main Application Window.

SYSTEM INTEGRATION

EPCC Console

Hardware modifications to the console are designed to minimize the risk, cost and time needed for installation. The switching assembly is assembled with highly reliable, mil-spec components to reduce the impact to system maintainability, reliability and performance. It installs on slides to allow easy access and the interface cables are designed to mate directly with existing cable assemblies. The new circuit card assemblies are designed with built-in, front panel connectors and install directly into spare slots of the existing processor chassis. Power requirements for the new equipment are designed to operate within the console's existing power capacity. All embedded training hardware can be installed and operated with the existing control software without affecting current operations.

The most difficult part of integrating embedded training hardware with this legacy system was to maintain hardwired control and monitoring capability during normal operations while providing processor control of the switches and indicators during embedded training mode. This was accomplished by inserting a switching relay in the path of the hardwired signals within the console.

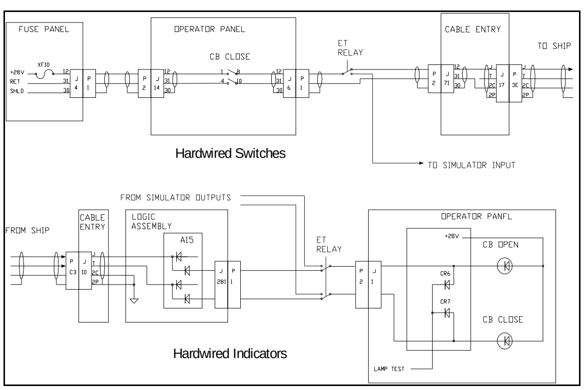

Figure 7 Typical Hardwired Circuits

For hardwired switches and pushbuttons, the switching relays disconnect the output signals prior to exiting the console and redirect them to the simulation when energized as shown in Figure 7. This allows the console controls to be activated and monitored while in ET mode without affecting the real ship's equipment. For hardwired indicators, the relays interrupt the input signals from the ship's equipment and allow simulation outputs to control the status of the indicators. The placement of the relay contacts as shown in Figure 8 provides the added benefit of allowing the processor to continue monitoring the real status from the ship's equipment while controlling the console indicators with simulated data.

Normally, the synchroscope connects to the output of the ship's generators and displays the phase and frequency relationship between the two AC sources as shown in Figure 8. During ET mode, two custom-designed, frequency-controlled sine wave generators are utilized to produce very precise sine wave signals.

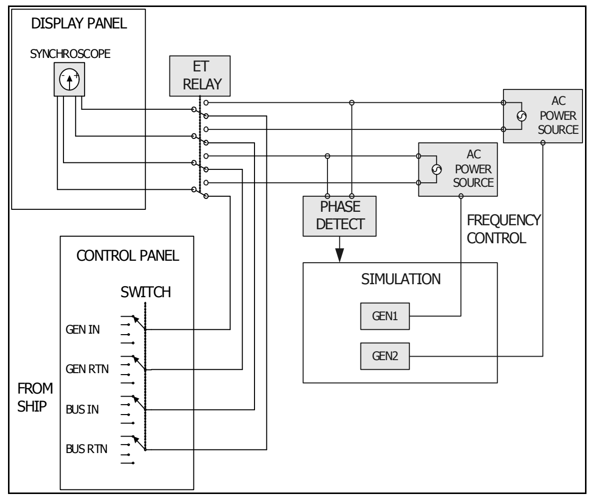

Figure 8 Synchroscope Stimulator

The frequencies are controlled by the simulation and an in-phase detector circuit provides a signal to the simulation when the phase difference of the two signals is within the allowable window. As in the discrete signals, switching relays disconnect the real signals and connect the simulated signals during ET mode. This hardware-in-the-loop approach simplifies the simulation software and generates precisely controlled sine waves to provide realistic operation of the synchroscope during training.

TIWS Creation and Integration

The TIWS Computer Software Configuration Item (CSCI) is a combination of Computer Software Components (CSC) that runs on a laptop allowing an instructor to initiate and perform training exercises with an EPCC operator. The CSCs are the Executive, FODMS Input/Output, Operator Interface, Data Logging, and Plant Simulation. The TIWS CSCI allows the instructor to perform two modes of training; signal insertion and simulation training.

Signal insertion training is performed while the EPCC is monitoring and controlling the live electric plant systems and allows the instructor to override any signal in the plant to train the EPCC operator on single or multiple EOSS procedures. Simulation training is performed with all plant systems in local control and all EPCC monitoring and control signals redirected from the live plant to the plant simulation running on the TIWS. Simulation training allows the instructor to perform all EPCC EOSS procedures without placing plant equipment at risk of damage by inappropriate EPCC operator actions.

Providing the capability of simulation training in a legacy system created challenging integration issues such as; integrating converted simulation C code and stepping the code in a Windows environment, interfacing the different software applications, and integrating different Graphical User Interfaces (GUI) into one coherent interface.

Integrating Simulation Code

The simulation the EPCC interacts with is part of the Plant Simulation CSC consisting of simulation code, support libraries, and a simulation manager to handle I/O and timing of the simulation. The MatLab application Simulink provides a Generic Realtime Workshop (GRT) tool that converts from block diagram model format to C code resulting in the simulation code that is integrated.

The first challenge with integrating the generated simulation C code into the TIWS is the hard-coded inputs and outputs of the simulation code requiring individual assignment of each input and output. This required a very time intensive setup and created a tedious maintenance issue. There are over 1500 signals for the EPCC plant simulation. In order to maintain this matching I/O interface, a signal list was created and requires updating each time an input or output of the simulation is changed. Along with the signal list changes a number of hard-coded interface functions require updating.

A second challenge with the integration of the simulation code is running the simulation software in a real-time manner on the non-real-time operating system Windows XP. In order for the simulations to provide realistic results the simulation must be accurately stepped. Since Windows XP does not provide real-time operations a method using functions to access the system clock is used to monitor the duration of each cycle through the process of writing inputs to, stepping, then reading the outputs of the simulation. The new method provides the accuracy required and overcomes the lack of real-time operations in the operating system.

Software Interfaces

The TIWS executes four separate applications that include the TIWS workstation providing the instructor GUI, the communication application facilitating communications to and from the EPCC and maintaining the system time and date, the subsystem manager updates the EPCC subsystem graphics and the simulation manager provides data to and gets data from the embedded simulation software at periodic intervals.

The TIWS workstation application is executed first and allows the instructor to select the hull number of the ship on which embedded training is to be performed. The TIWS workstation application then spawns each of the other applications with the hull number information allowing each application to be initialized with the same signal definition.

One of the challenges faced with the software interfaces is how to efficiently pass the data between the four different applications running on the TIWS. The use of shared memory and a common signal database is implemented affording each application a seamless interface without the complexity of prototype definitions. The applications that share data with each other use the same common signal database. This creates one excel document that is easy to update and maintain. The use of semaphore locking guarantees safe access to data between all the applications.

Integrating Multiple GUI Applications

The Operator Interface is comprised of Graphics User Interfaces developed using two COTS products; Microsoft Visual Studio and Altia. Microsoft. Visual Studio allows development of the main application window components and layout and all dialogs. Altia allows the development of console specific graphics layout, color and behaviors. Altia resources are provided and callable from an Altia API and runtime environment. Coordinating the events of the two separate applications requires handling two separate software threads and separate event handling functions. The additional complexity and maintenance added by having two different products is outweighed by the GUI performance. The GUI is both intuitive and familiar due to the reuse of subsystem windows that reside on the EPCC GUI.

Communications Messages

Communications between the TIWS and EPCC is directly handled by the communications application. Embedded training messages are exchanged eight times a second to provide realistic response to the console operator and feedback to the simulation or instructor depending on the embedded training mode. The console real data is provided to the instructor during simulation mode to ensure the actual ship's electric plant is operating normally and allow the instructor to abort embedded training in case of a problem detected with the actual electric plant.

RESULTS

The ETS for the EPCC underwent Unit Testing at Lockheed Martin's Simulation Training & Support test berth facilities and was moving into System Integration and Test (SIT) the final phase before delivery to the customer when this paper was completed. Unit test was performed on an EPCC with all of the hardware modifications completed and connected to the FODMS. Each requirement was tested with the TIWS connected to the EPCC through the FODMS similar to the ship's configuration.

Unit testing went well with only a few challenges. The synchroscope was one of the most challenging interfaces to support. The synchroscope is an electromechanical meter that has a needle that responds to frequency and phase differences between two sources. The meter is used for determining when two sources on either side of a circuit breaker are in phase and the circuit breaker can be closed safely. To drive this meter hardware had to be added to the EPCC in order to drive the 120 volt AC inputs. The outputs of the simulation providing the simulated sources must leave the TIWS go through the FODMS into the EPCC to drive the hardware for the meter. The response back from the hardware to the TIWS must be quick enough so the simulation can respond to the hardware changes. The communications rate of 8 times per second did allow the meter to move as it would on a ship with live hardware driving the meter, but many tweaks had to be made in both the simulation and the hardware in order for the meter to perform realistically.

SUMMARY

The performance and functionality specified in the requirements of the ETS were successfully demonstrated during unit testing. The remaining System Integration and Test was not completed as of this papers completion. LM STS is confident after the success of unit testing that SIT will also be successfully completed and the ETS will be delivered on time to the customer's first installation aboard DDG-96.

CONCLUSION

Development of the Embedded Training capability for the DDG Machinery Control System requires a diversified engineering group to address multiple technical areas. The following list describes some of the major development challenges and also approaches to resolve issues.

- It is critical to completely understand the operational aspects of the system including the physical plant behavior and the control system. Achieving this understanding requires expertise in multiple domains. This group of experts includes the control system engineering, ship equipment designers and operators.

- It is as equally important to understand the operator training requirements and be able to define these requirements succinctly to facilitate system design, test, and validation. Requirements definition involves inputs from the same diverse group of experts as listed in the previous paragraph.

- The need to determine how accurate the simulation models need to be to support realistic training scenarios. Models that have lower fidelity but meet accuracy performance tend to be less expensive to develop.

- Integration of multiple hardware, software, and network components that exist in the DDG Machinery Control System require some level of prototyping up front to ensure success.

REFERENCES

NAVSEA Philadelphia, Operational Sequencing System – CD ROM for DDG-94 USS NITZE, DECEMBER 13, 2004.