RTDS Implementation of Notional Four Zone MVDC Shipboard Power System

RTDS Implementation of Notional Four Zone MVDC Shipboard Power System

Document for the
ESRDC Team

02/22/2018
Version 1.0

REVISION HISTORY

Personnel

VERSION NUMBER	DATE	COMMENTS
1.0	02/23/18	• Working version of the document • Verification and validation results to follow in later revisions

Table of Contents

Table of Contents ii
1 RTDS Implementation of Four Zone Notional MVDC Model 2
2 Module Implementation 4
2.1 Power Generation Module 4
2.1.1 Thyristor Controlled Rectifier based PGM 4
2.2 Power Conversion Module-1A with IPNC 5
2.3 Propulsion Motor Module 7
2.4 Rail Gun Module 9
3 References 10

Terminology and Acronyms

FSU	Florida State University
CAPS	Center for Advanced Power Systems
MVDC	Medium Voltage DC
DC	Direct Current
AC	Alternating Current
SPS	Shipboard Power System
RTDS™	Real Time Digital Simulator from RTDS Technologies, Inc.
DRTS	Digital Real Time Simulator
CHIL	Controller Hardware-in-the-Loop
PGM	Power Generation Module
PCM-1A	Power Conversion Module
PMM	Propulsion Motor Module
PCC	Point of Common Coupling
MMC	Modular Multi-level Converter
TCR	Thyristor Controlled Rectifier
IPNC	Integrated Power Node Center
RoS	Rest of System
EMRG	Electromagnetic Rail Gun
ms, msec	milliseconds

1 RTDS Implementation of Four Zone Notional MVDC Model

The data provided in the Notional Four Zone MVDC Shipboard Power System Model document [1], [2] is utilized to implement a real-time model of shipboard power system in RTDS. The RTDS model is aimed to run in real-time with a time-step of 50 µsec with sections of model running with smaller time-step size of 1-2 µsec as required. The SPS model spans across 5 racks. Figure 1 shows the notional four zone MVDC SPS model while Figure 2 depicts the implementation of system model spread across RTDS racks. Rack 3 consists of zonal structure of SPS with all four zones modeled with switchboards along with PMM, and EMRG. Rack 4 and 5 consists of three main PGMs and two auxiliary PGMs. PCM-1As with IPNC from zone 1 and zone 2 are modeled in racks 1 while PCM-1As with IPNC from zone 3 and zone 4 modeled on rack 5. Most of the modules in the SPS are interfaced to the zonal structure through the use of cross rack transformers. Implications of using cross-rack transformer which adds additional and unnecessary inductance and capacitance into the system in case of real-time simulation requirement is explained is kept to a minimum by incorporating stray elements into model parameters. Control systems implementation will be spread throughout the racks where necessary and as required. Naming convention and schemes were adopted to the model for ease of implementation, replication and modification.

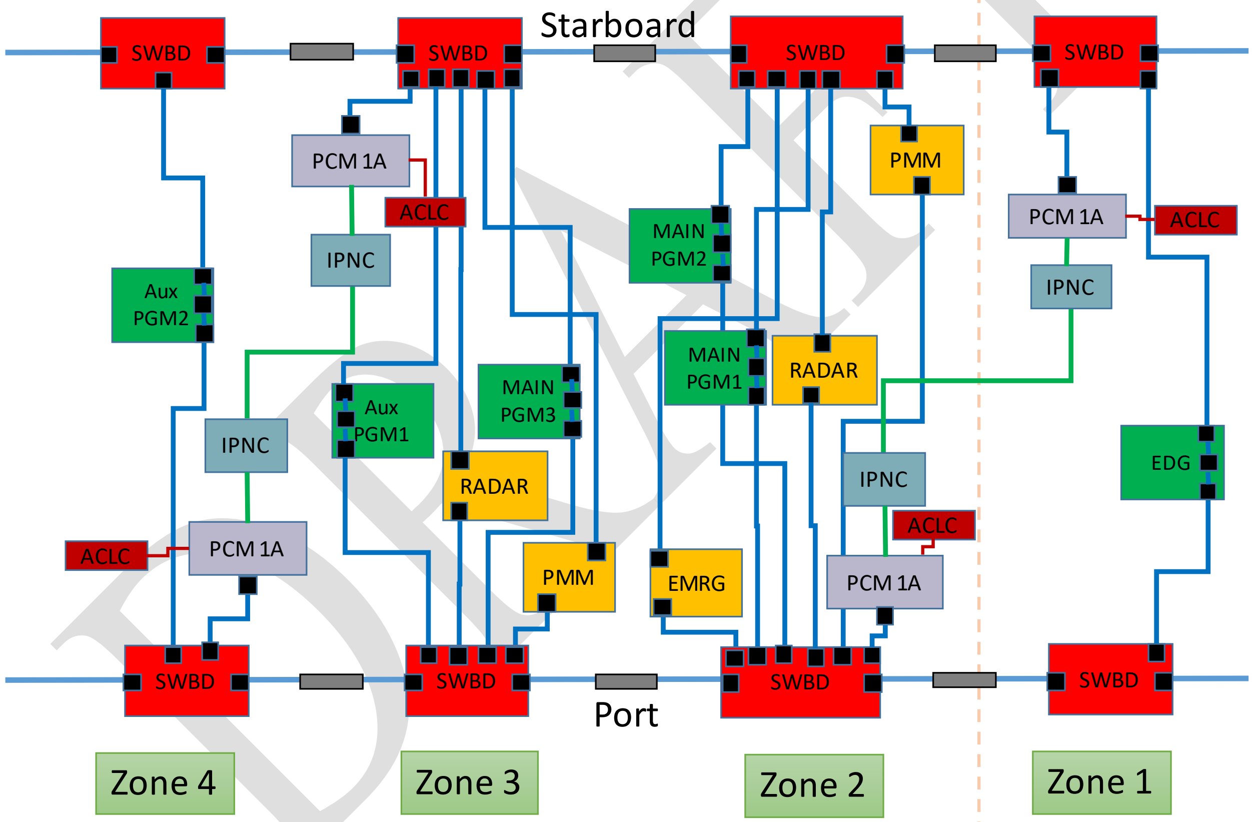

Figure 1 Power system module layout and distribution across racks for RTDS implementation

Each of the various modules of the model were implemented separately and tested for their operations. The following sections provide the information regarding modeling of the SPS components and modules in RTDS.

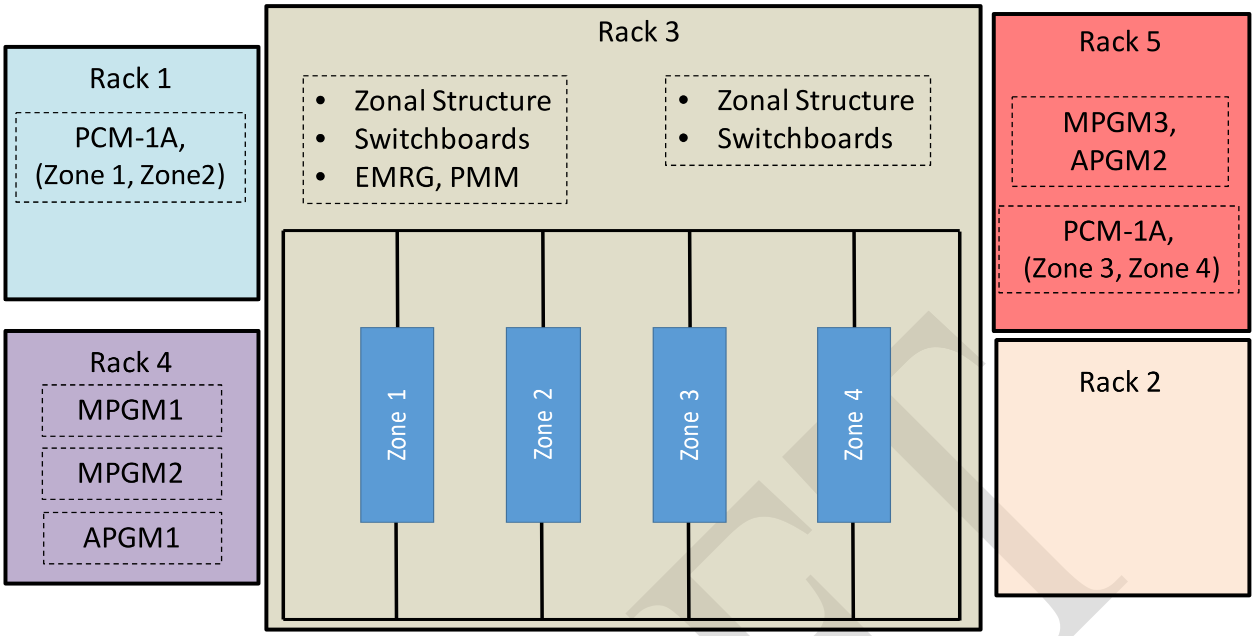

Figure 2 Power system module layout and distribution across racks for RTDS implementation

While modeling of systems and modules has been described in this document, an important aspect of conducting simulations in RTDS is to be able to easily allow for simulation traceability, repeatability, and ease of execution of parametric studies. In order to achieve these, a set of functions and scripts have been utilized. These scripts allow for setting of module parameters through scripts rather than setting values through RSCAD GUI.

2 Module Implementation

This section provides information regarding implementation and performance of modules in RTDS.

2.1 Power Generation Module

Two versions of PGM are available, a thyristor controlled rectifier (TCR) and a modular-multilevel converter (MMC) based PGM. Implementation of each module is different and explained below.

2.1.1 Thyristor Controlled Rectifier based PGM

The main generator modules (MPGM) and auxiliary generator modules (APGM) both use multiphase machine model with a single shaft gas turbine for the prime mover (GAST model) and IEEE Type AC8B exciter to which two independent TCR models are interfaced thereby providing two independent outputs from PGM. The TCR PGM is modeled in small time-step with a step-size of 1.8 µs. The module is interfaced to the rest of the system in large time-step through two transformers. Interface transformers (I-Trx) provide link between small and large time step while cross rack transformers (XR-Trx) link PGM output terminal to required zones. The time step environment with a time step of 2 µs interfaced to the rest of the system through large time step environment with a time step of 50 µs. Figure 3 shows the block diagram implementation of PGM in RTDS. To keep the unnecessary inductance and capacitance from transformers to a minimum, the filter components of the PGM are incorporated into the interface and cross rack transformers.

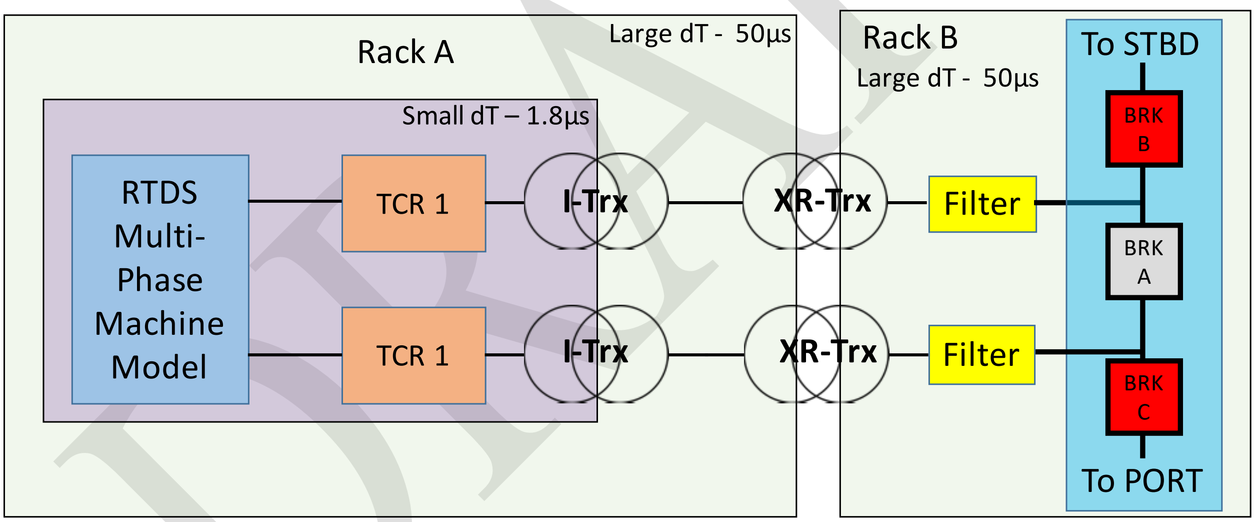

Figure 3 Block diagram of implementation of PGM in RTDS

Table 1 provides high level outline of parameters used for main PGM while Table 2 provides data for auxiliary PGMs.

Table 1. Information for main PGM

Parameter	Value
Rated apparent power (MVA)	36.5
Rated output power (MW)	29
Rated Voltage (L-L, RMS)	9.8 kV
Rated Frequency (Hz)	120
Rectifier 1, 2 rating each (MW)	15
PGM DC output voltage (kV)	12

Filter Capacitor (µF)	825
Rectifier output DC reactor (µH)	790

Table 2. Information for auxiliary PGM

Parameter	Value
Rated apparent power (MVA)	6.25
Rated output power (MW)	5
Rated Voltage (L-L, RMS)	9.8 kV
Rated Frequency (Hz)	120
Rectifier 1, 2 rating each (MW)	2.5
PGM DC output voltage (kV)	12
Filter Capacitor (µF)	825
Rectifier output DC reactor (µH)	790

2.2 Power Conversion Module-1A with IPNC

A simplified mathematical model of a PCM-1A has been implemented in RTDS with enough detail to capture effect of loads within PCM-1A on to the 12 kV MVDC distribution bus. Figure 4 shows the block diagram of PCM-1A as envisioned in the MVDC SPS model document while Figure 5 shows implementation of PCM-1A in RTDS. The PCM-1A models consists of a 12 kV connection from specific zone from the MVDC distribution and models the 1 kV DC bus, MW class loads, AC load center and its 450 V loads, and the integrated power node center. The IPNC module is integrated inside PCM-1A for the current implementation method.

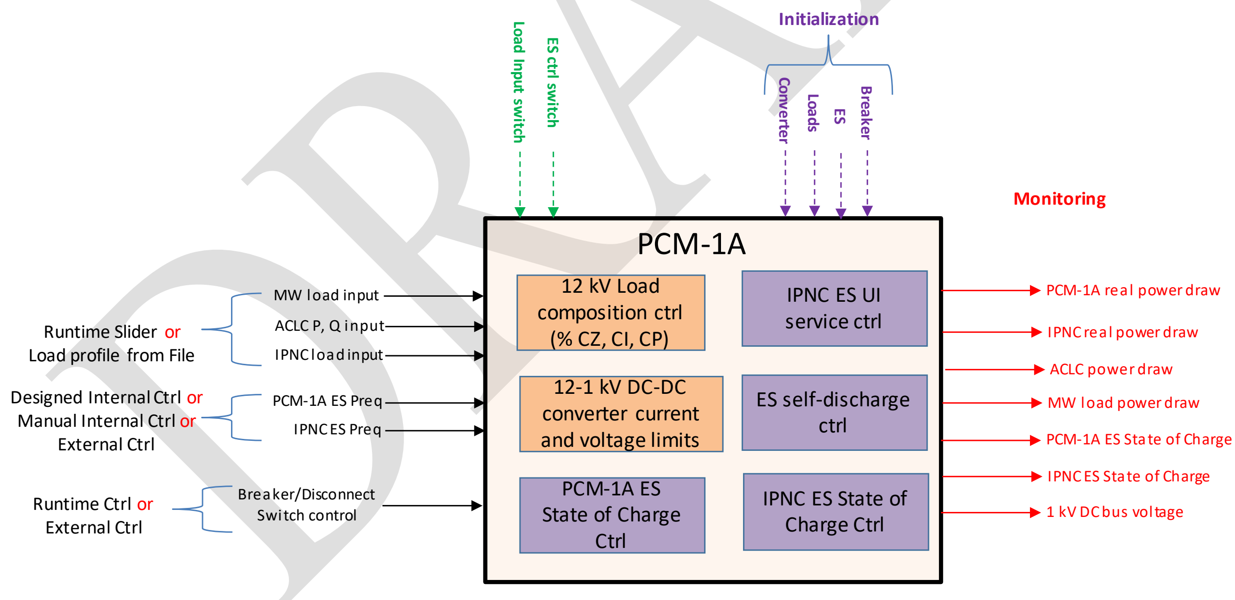

Figure 6 PCM-1A options in RTDS

Table 3 provides high level overview of ratings of PCM-1A in each zone.

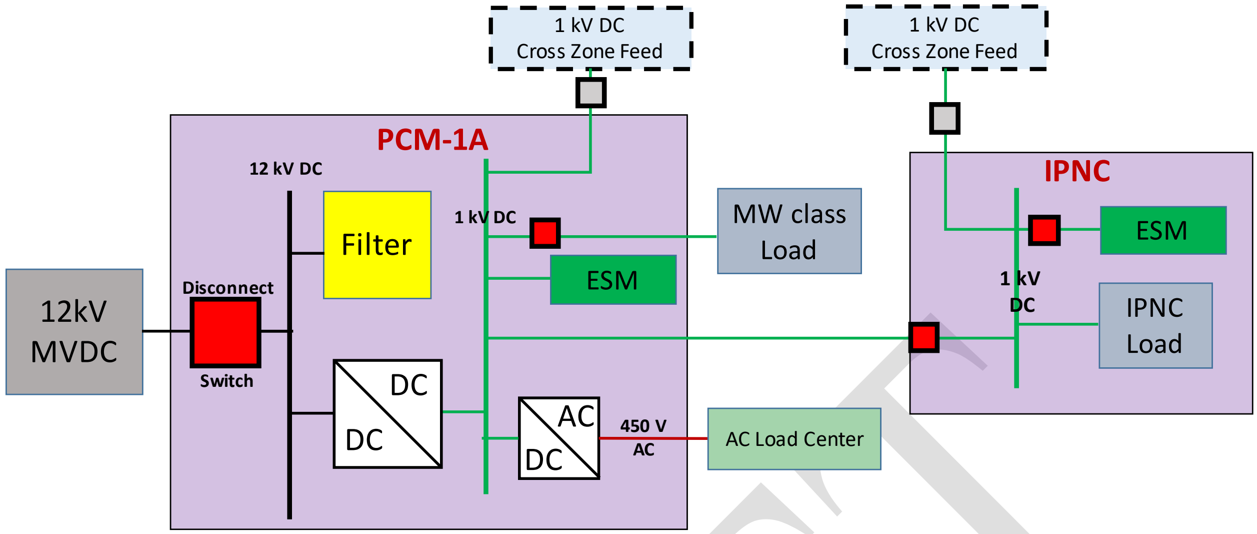

Figure 4 Block diagram envisioned PCM-1A in MVDC SPS model

Since switching converters are not modeled explicitly in PCM-1A, coupling between different voltage levels is accomplished using voltage source-current source coupling interface. The 12-1kV dc-dc converter, ACLC converters are implemented using the above mentioned interface. Converter current limits as well as voltage drop off w.r.t load current is implemented. Breakers/disconnect switches are modeled such that isolation of 1kV DC bus, loads and energy storage modules can be accomplished. The PCM-1A along with IPNC also has a cross zone/neighbor zone 1kV DC feed for which the breaker/disconnect is normally open. The implementation in RTDS allows for internal or external control of energy storage, loads, and breakers so that controller and power hardware-in-the-loop (CHIL and PHIL) experiments can be explored. Figure 6 shows the PCM-1A model control options as modeled in RTDS.

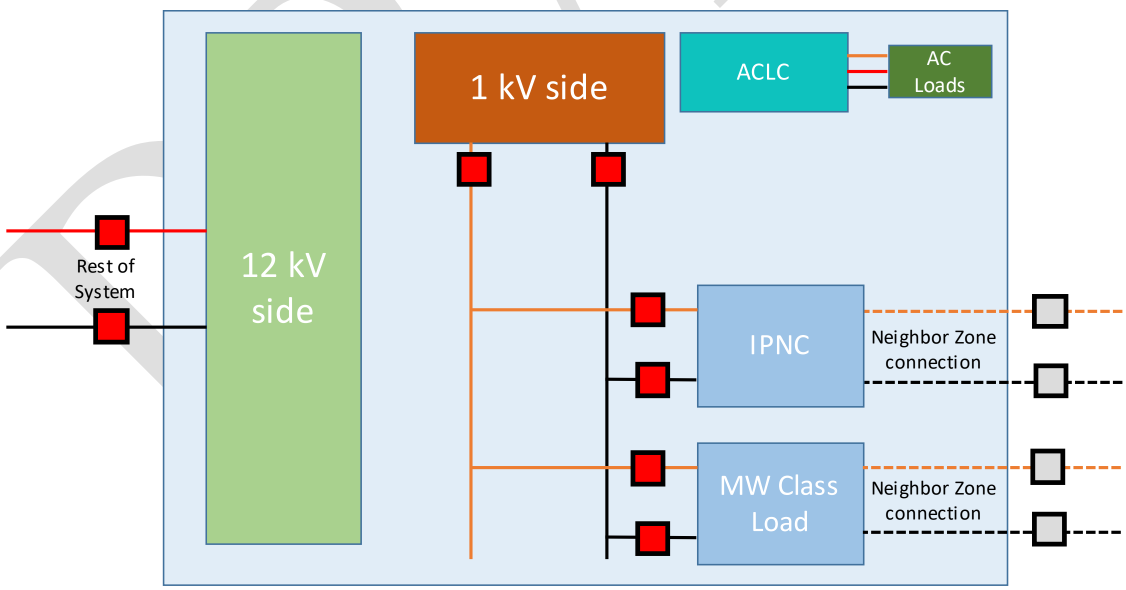

Figure 5 Block diagram of implementation of PCM-1A

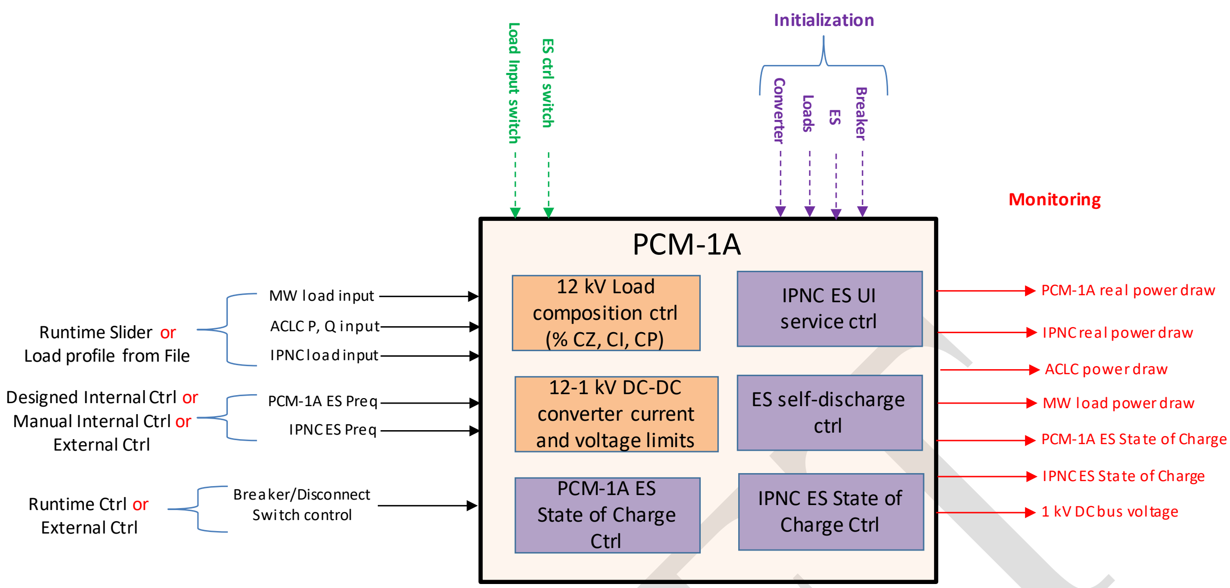

Figure 6 PCM-1A options in RTDS

Table 3. PCM-1A ratings

	Zone 1	**Zone 2**	**Zone 3**	**Zone 4**
PCM-1A rating (MW)	10.64	10.64	9.17	9.17
IPNC rating (MW)	2.77	3.13	3.95	1.99
PCM-1A energy Storage rating (MJ)	5	5	5	5
IPNC energy storage rating (MJ)	3	4	4	2
MW class load rating (MW)	5	4	2	4
ACLC load rating (MW)	2.75	3.25	3.0	3.0
12-1 kV dc-dc converter current limiting (pu)	1.1			
Energy Storage ramp rate (MW/sec)	5	5	5	5
Energy Storage self-discharge time (hours)	10000	10000	10000	10000
Mission loads (in IPNC)	VLS, SONAR			

2.3 Propulsion Motor Module

Two propulsion motor modules (PMM), one in zone 2 and one in zone 3 are modeled in RTDS. The Modules convert speed input to the model into a power drawn from the system through the use of motor, motor drive efficiency curves and the propulsion motor speed-power curve provided in S3D. Hydrodynamics associated with propulsion systems is currently not modeled but will be incorporated in future revisions of the model. Each PMM module is modeled as current source interface to MVDC system and each module power draw is split equally between port and starboard system. Figure 7 provides information regarding modeling of PMM in RTDS. Table 4 provides data used for motor speed-power curve while Table 5 provides data used for motor efficiency curve with respect to its load. The motor drive efficiency is fixed at a constant 98%.

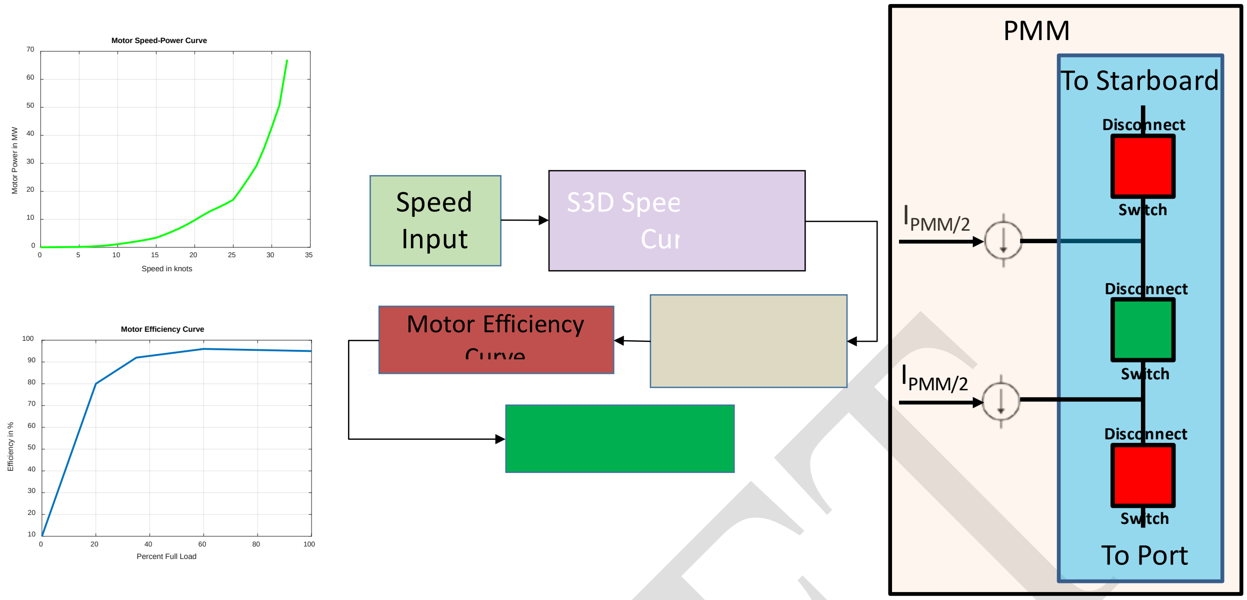

Figure 7 PMM implementation in RTDS

Table 4. PMM motor speed-power curve

Speed (knots)	Power (kW)	Speed (knots)	Power (kW)
0	10	19	8,157
5	138	20	9,698
6	241	21	11,359
7	372	22	12,894
8	534	23	14,151
9	794	24	15,482
10	1,121	25	17,004
11	1,502	26	20,755
12	1,918	27	24,780
13	2,359	28	29,074
14	2,851	29	35,362
15	3,432	30	42,840
16	4,434	31	50,811
17	5,543	32	67,000
18	6,760		

Table 5. PMM motor efficiency curve

% Load	Efficiency (%)
0	10
20	80
35	92
60	96
100	95

2.4 Rail Gun Module

The rail gun module (EMRG) is modeled in zone 2. The rail gun draws power equally through both port and starboard bus. Figure 8 shows the rail gun implementation in RTDS. The rail gun module consists of two energy storage elements, an energy dense unit (ESa) used to charge the power dense pulse forming network energy storage unit (ESb). The sizing of the storages are determined based on the estimation that the rail gun needs an output power of 33 MW with a 33% efficiency for each firing pulse. A total of 50 pulses must be supported by the EMRG system. Table 6 provides information regarding parameters of the EMRG system.

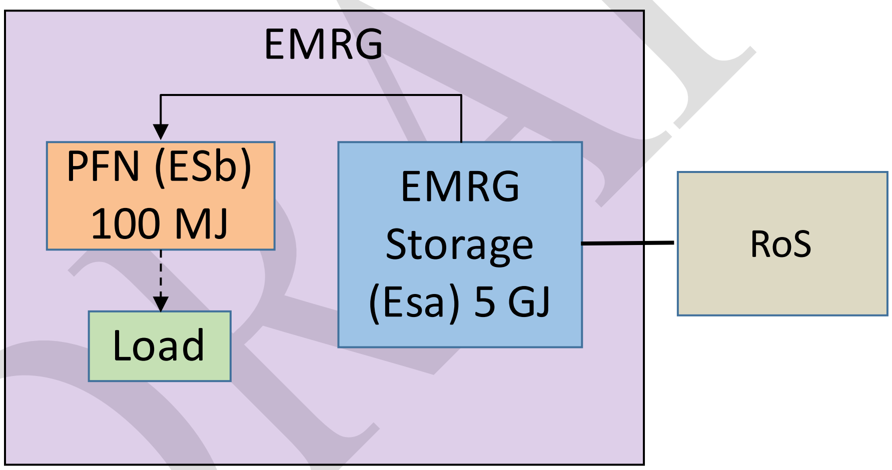

Figure 8 EMRG implementation in RTDS

Table 6. EMRG module parameters

Parameter	Value
EMRG interface converter	30 MW
Energy storage 1	5 GJ
Energy storage 2	100 MJ
Rail gun output	30 MW

Figure x shows the operation of EMRG in RTDS. The EMRG can be operated in charge mode where in it can charge energy storage ESa or discharge ESb to provide support to rest of power system. In fire mode, the ESa will charge ESb to full charge and enable firing of rail gun. The actual pulse load itself is not explicitly modeled and is accomplished by changing state of charge of ESb from 1 (fully charged) to 0 (discharged, indicating firing of gun).

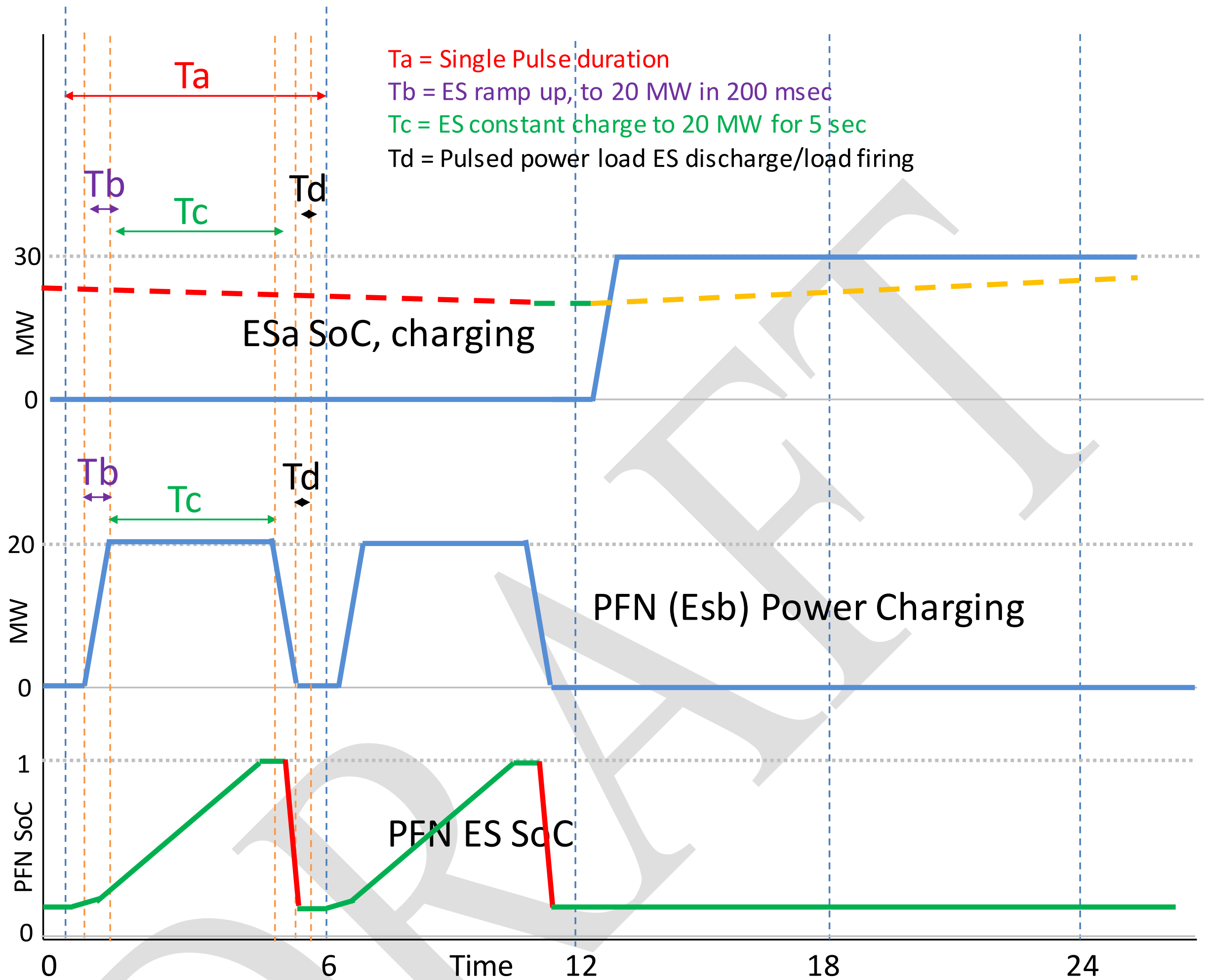

Figure 9 EMRG operation in RTDS

3 References

[1]. Julie Chalfant, et al., "Draft ESRDC Initial Notional Ship Data", https://esrdc.com/library/?q=node/762.

[2]. ESRDC companion dynamic model for the notional ship data presented in S3D.