OPAL-RT Implementation of Notional IPES – Simplified Model

Document for the
ESRDC Team

06/11/2018
Version 1.0

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REVISION HISTORY

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VERSION NUMBER	DATE	COMMENTS
1.0	06/11/18	• Working version of the document • Verification and validation results to follow in later revisions

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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
OPAL-RT™	Real Time Digital Simulator from OPAL-RT Technologies,
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 OPAL-RT 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 simplified model of shipboard power system in OPAL-RT. The OPAL-RT model is aimed to run in real-time with a time-step of 50 µsec. The SPS model was developed in a single Opal-RT Module 4510. Figure 1 shows the notional four zone MVDC SPS model. Naming convention and schemes were adopted to the model for ease of implementation, replication and modification.

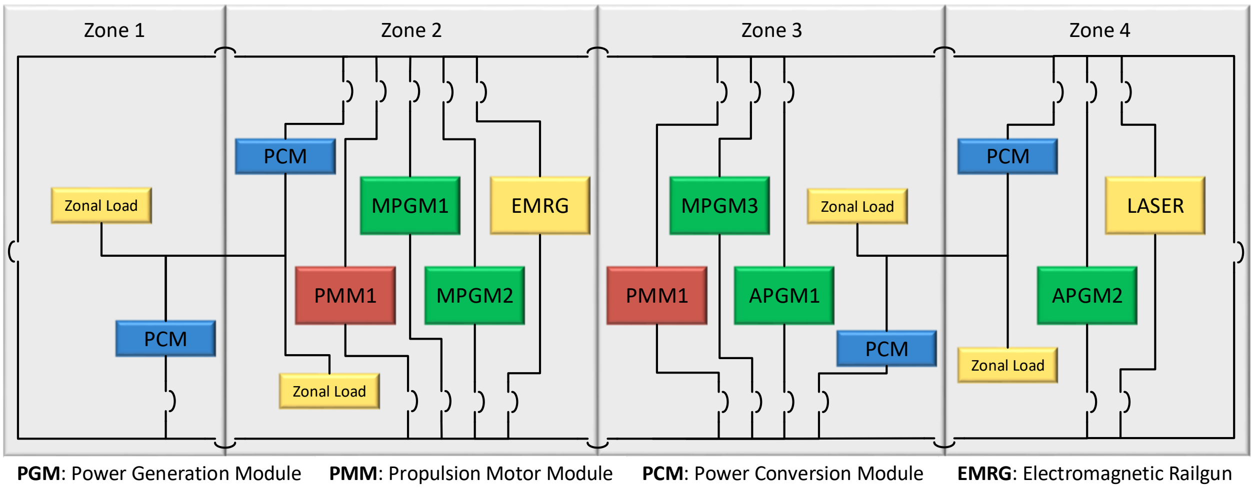

Figure 1 Power system module layout and distribution for OPAL-RT implementation

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 OPAL-RT.

While modeling of systems and modules has been described in this document, an important aspect of conducting simulations in OPAL-RT is to be able to easily allow for simulation traceability, repeatability, and ease of execution of parametric studies.

2 Module Implementation

This section provides information regarding implementation and performance of modules in OPAL-RT.

2.1 Power Generation Module

The main generator modules (MPGM) and auxiliary generator modules (APGM) both use ideal DC voltage source model with internal impedance. Figure 2 shows the block diagram implementation of PGM in OPAL-RT.

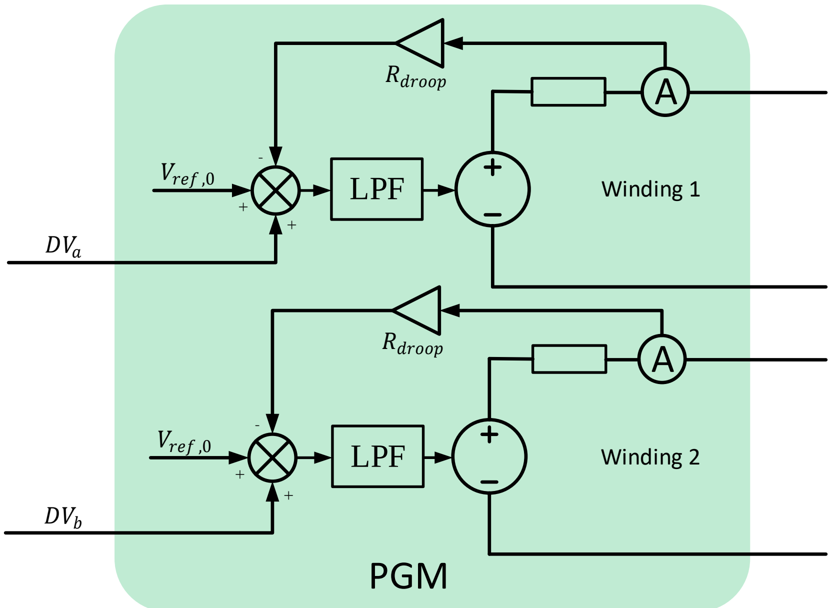

Figure 2 Block diagram of implementation of PGM in OPAL-RT

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 output power (MW)	34.48
Rectifier 1, 2 rating each (MW)	17.24
PGM DC output voltage (kV)	12
Line Resistance (Ω)	0.01
Line Inductance (mH)	0.1
LPF Time Constant (s)	0.001

Table 2. Information for auxiliary PGM

Parameter	Value
Rated output power (MW)	4.48
Rectifier 1, 2 rating each (MW)	2.24
PGM DC output voltage (kV)	12
Line Resistance (Ω)	0.01
Line Inductance (mH)	0.1
LPF Time Constant (s)	0.001

2.2 Power Conversion Module-1A with IPNC

A simplified mathematical model of a PCM-1A has been implemented in OPAL-RT with enough detail to capture effect of loads within PCM-1A on to the 12 kV MVDC distribution bus. Figure 3 shows implementation of PCM-1A in OPAL-RT. 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 loads, and the integrated power node center. The IPNC module is integrated inside the PCM-1A and zonal loads for the current implementation method. Table 3 provides high level overview of ratings of PCM-1A in each zone.

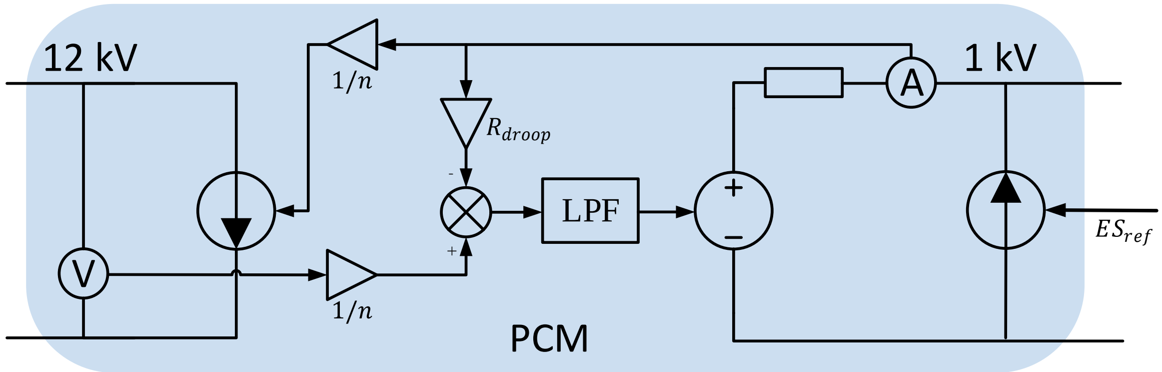

Figure 3 PCM-1A implementation in OPAL-RT

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 converters are implemented using the above mentioned interface. Converter current limits as well as voltage drop off w.r.t load current has not been implemented. The parameters for the line impedance and low-pass filter constants on the voltage-source side of the interface are the same as for the PGMs from Table 1. The implementation in OPAL-RT 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.

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
PCM-1A energy Storage rating (MJ)	5	5	5	5
MW class load rating (MW)	5	4	2	4
ACLC load rating (MW)	2.75	3.25	3.0	3.0
Energy Storage ramp rate (MW/sec)	5	5	5	5
Energy Storage self-discharge time (hours)	10000	10000	10000	10000

2.3 Propulsion Motor Module

Two propulsion motor modules (PMM), one in zone 2 and one in zone 3 are modeled in OPAL-RT. Each PMM module is modeled as constant power load interface to MVDC system and each module power draw is split equally between port and starboard system. Figure 4 provides information regarding modeling of PMM in OPAL-RT. 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%.

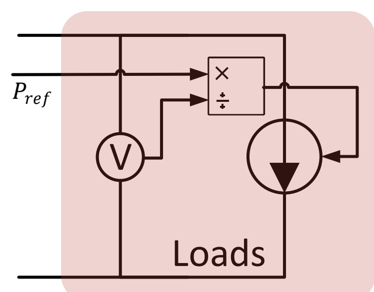

Figure 4 PMM implementation in Opal-RT

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. The railgun module in this model is developed similar to the other loads (as shown in Figure 4), with the addition of an energy storage device connected in parallel to the load, modeled as a controllable current source. Since the multiple stage energy storage utilized in the actual railgun is not shown, the pulse forming network (PFN) is incorporated into the power profile for the railgun. This presents the charging and discharging load for the PFN as the load on the rest of the system, resulting in the operation shown in Figure 5. The resulting profile shows that the PFN is charged at 20 MW for 5 seconds, and then discharged for 1 second as the railgun is fired. This process is repeated for each firing of the railgun.

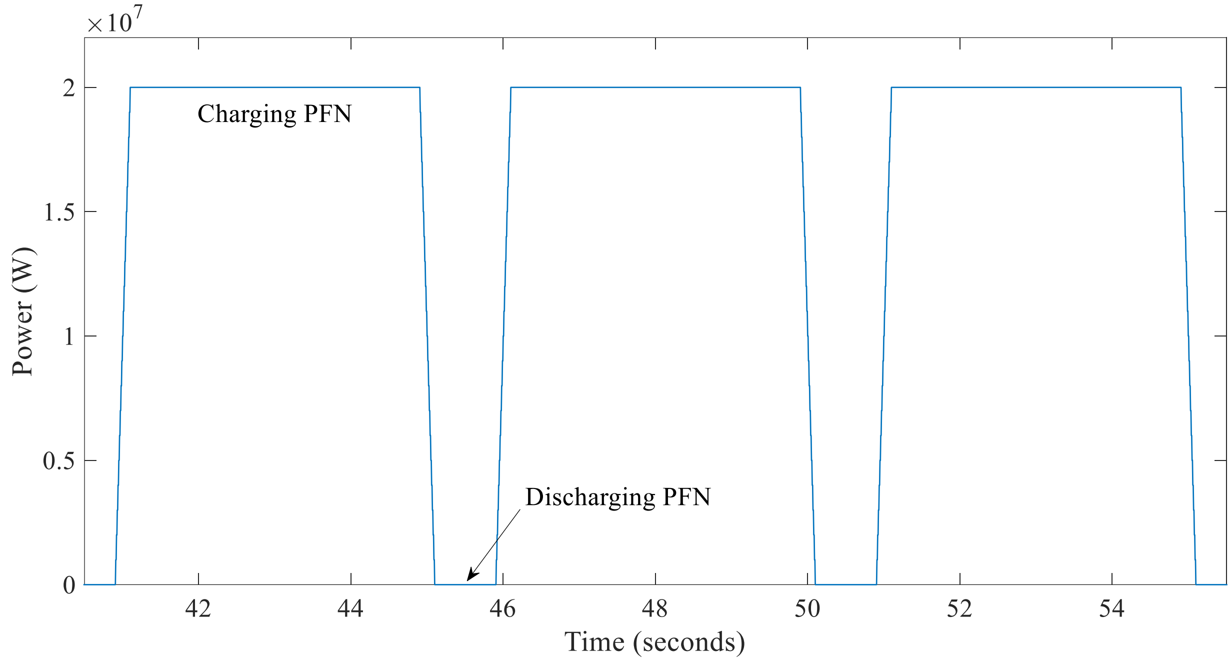

Figure 5 EMRG operation in OPAL-RT

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.