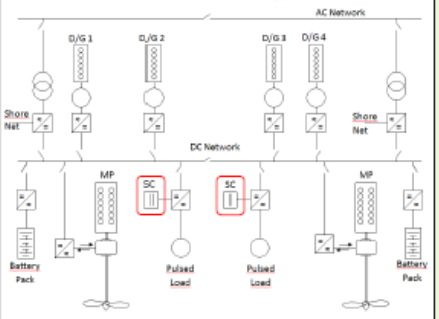
ULTRA-CAPACITOR MODELS

FOR ALL ELECTRIC AND HYBRID SHIP POWER SYSTEMS

Main Objective: Experimental comparison of ultra-capacitor models supporting all electric/hybrid propulsion and on board MVDC distribution marine systems in hybrid energy storage configuration.

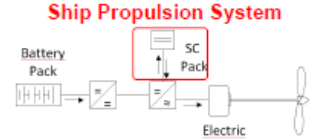
EXEMPLES OF APPLICATIONS: ELETTRIC/HYBRID SHIP POWER SYSTEMS

On-board Power System

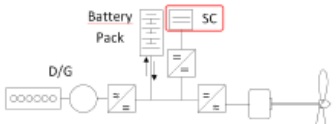


Application of Super-capacitors in On-Board MVDC Systems

Ship Propulsion System



Architecture of a Full Electric Ship with Batteries and Super-capacitors

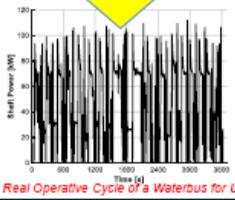


Architecture of a Hybrid Diesel Electric Ship With Batteries and Super-capacitors

Waterbus for Urban Transportation

ACTV Waterbus

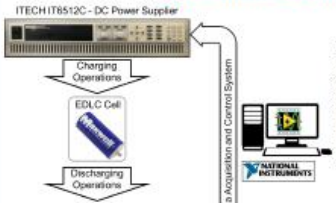
Venice Lagoon Waterborne Routes



High Dynamic Real Operative Cycle of a Waterbus for Urban Transportation

EXPERIMENTAL SET-UP

Experimental Tests on Single Cells

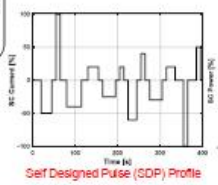


Test bench for storage cells/modules

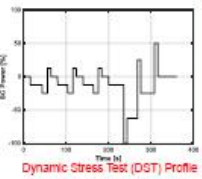
Maxwell BCAP3000 ultra-capacitor cell

Rated Capacitance [F]	3000
Rated Voltage [V]	2.70
DC Equivalent Series Resistance [mΩ]	0.29
Weight [g]	510
Maximum Leakage Current [mA]	5.20
Stored Energy [Wh]	3.04
Specific Energy [Wh]	6.00
Usable Specific Power [W/kg]	5900

Storage Cell Under Test

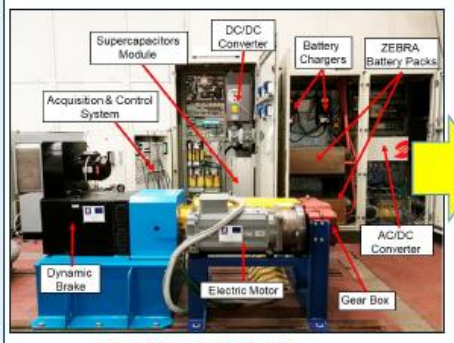


Self Designed Pulse (SDP) Profile

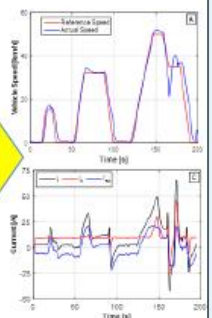


Dynamic Stress Test (DST) Profile

Experimental Tests on Super-cap modules in HESS



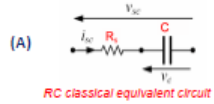
Dynamic Laboratory Test Bench for Hybrid Energy Storage Systems



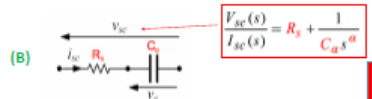
Experimental Results on ECE 15 Driving Cycle

MODELLING AND EXPERIMENTAL RESULTS

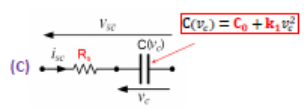
Super-capacitor Equivalent Circuits(*)



RC classical equivalent circuit

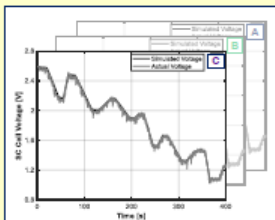


Equivalent Circuit of the super-capacitor RC fractional model

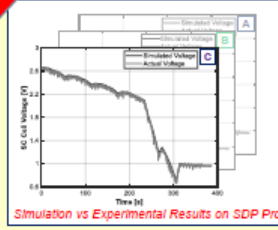


. Equivalent Circuit of the variable parameter model

(*)Identification of Parameters Obtained Through constrained Optimization Procedure Based on Experimental Tests



Simulation vs Experimental Results on DST Profile



Simulation vs Experimental Results on SDP Profile

Model Performance Evaluations

$$E_{avg} = 100 \cdot \frac{1}{N} \sum_{n=1}^{N} \frac{|v_{sc,n} - \overline{v}_{sc,n}|}{|\overline{v}_{sc,n}|}$$

$$E_{max} = \max_n \left(\frac{1}{N_s} \sum_{k=0}^{N_s} E_{avg,(n-k)} \right)$$

Fitting Performance Indexes

T_i=Simulation Time for the Model i-th

$$\tau_{s,i} = \frac{T_{min}}{T_i}$$

Computational Effort Index

Super-capacitor Model Comparison

	DST			SDP		
	E_{avg}	E_{max}	τ_s	E_{avg}	E_{max}	τ_s
RC Model (A)	3.01 %	6.44 %	0.49	4.09 %	7.75 %	0.52
RC Fractional Model (B)	2.53 %	3.97 %	1.00	1.40 %	2.57 %	1.00
Variable Parameters Model (C)	1.29 %	2.42 %	0.60	1.36 %	1.93 %	0.61

The obtained Results show that the variable parameter model (C), proposed in this paper, presents better fitting performance in comparison with both RC (A) and fractional order (B) model, with very low computational effort . In particular, for both SDP and DST test profiles, the value of error indexes is significantly reduced in comparison with RC model, whereas fitting performance of fractional and variable parameter models are quite similar.