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Energy Management of a Hybrid Tidal Turbine-Hydrogen Micro-Grid: Losses Minimization Strategy

Presentation Headlines

- ITEG Project Definition
- Studied System Architecture
- MW Scale PEM Electrolyzer Modeling
- Tidal Turbine Modeling & Control
- Results
- Conclusion

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ITEG: Integrating Tidal Energy into the European Grid

ITEG will develop and validate an **integrated hydrogen production solution** for clean energy generation and storage in remote areas facing grid export limitation.

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Project Objectives

- Open up new market opportunities for the ocean energy sector through energy storage
- Optimise the EMS and fast-track the integrated solution towards commercialisation
- De-risk future integrated energy generation and hydrogen storage projects
- Build a roadmap to support replication of ‘all-in-one’ solution across remote regions globally

Why Orkney?

- Lots of renewable energy resources; wave, tidal and wind

BUT….

- Remote, rural location
- Constrained grid

‘All-in-one’ solution

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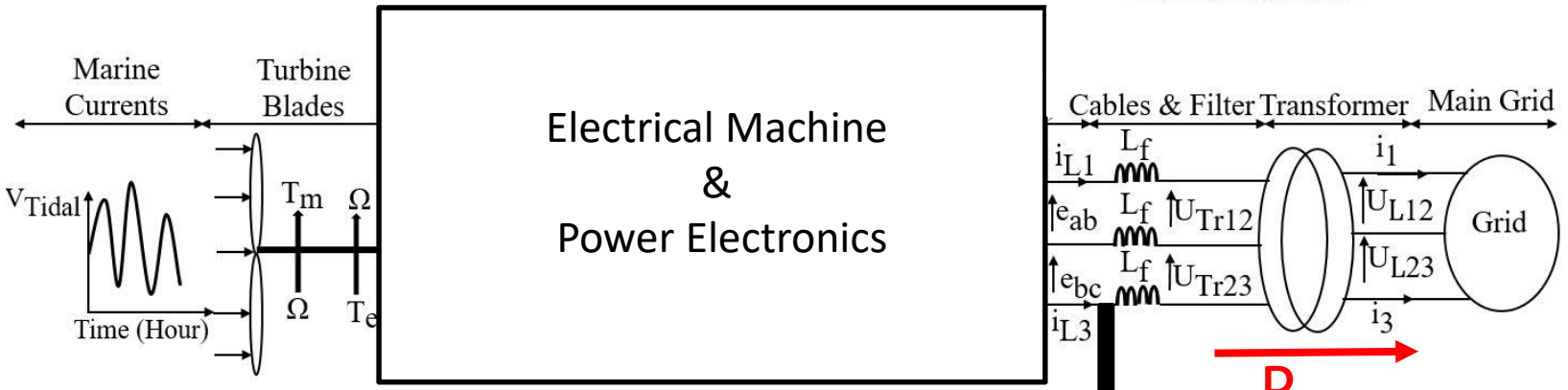
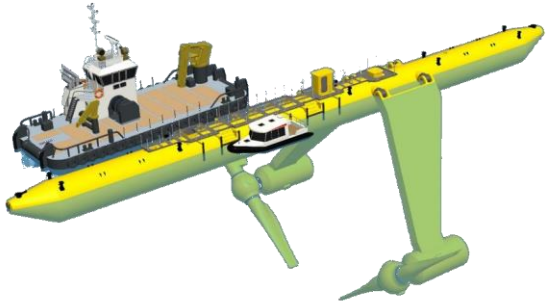
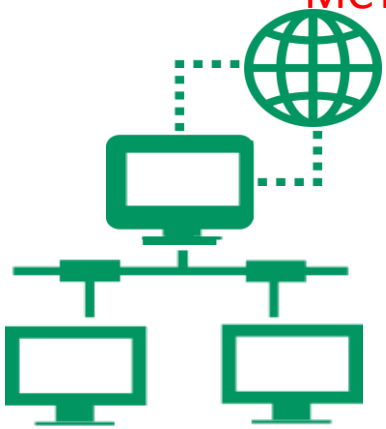




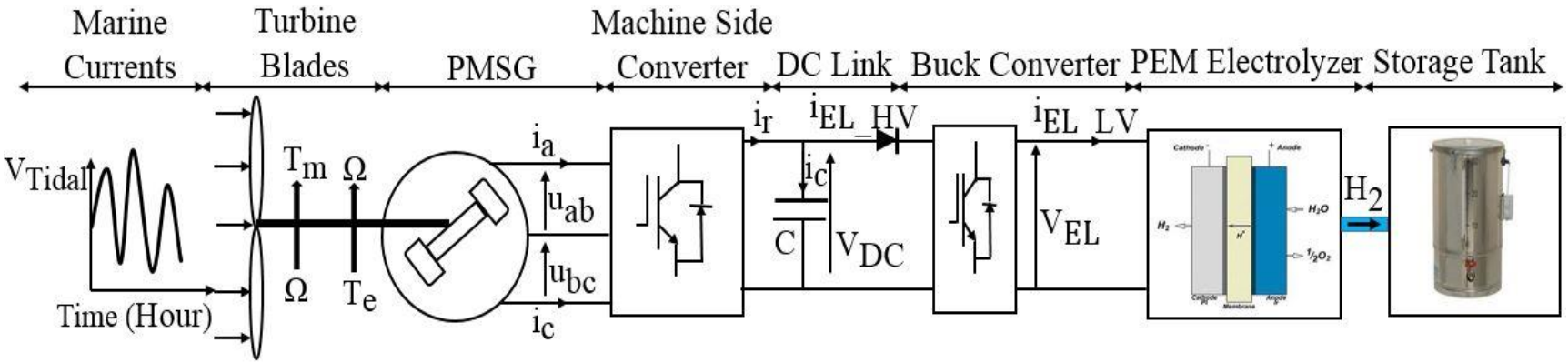
Orbital Marine Power ‘Orbital O2 2 MW’ tidal turbine



Smart onshore Energy Management System (EMS)

AREVA H2Gen 500kW electrolyser

Studied System Architecture



For evaluating initially the effect of the turbine control and management system on the hydrogen production during the standalone mode of operation

MW Scale PEM Electrolyzer Model

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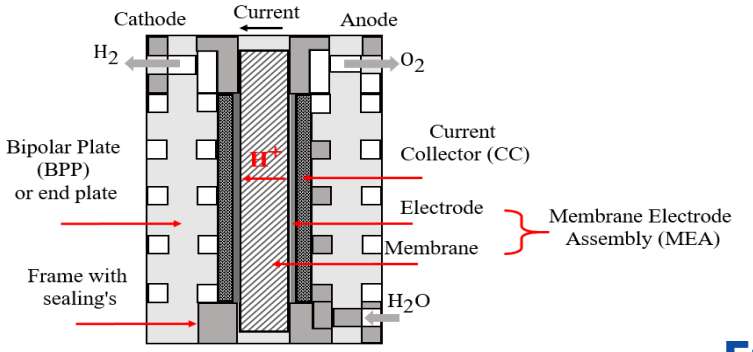
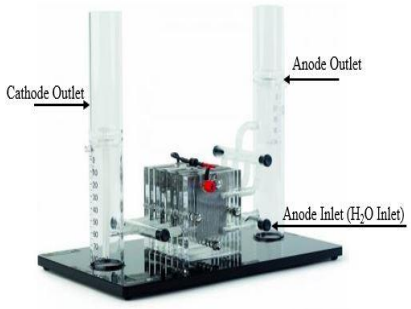
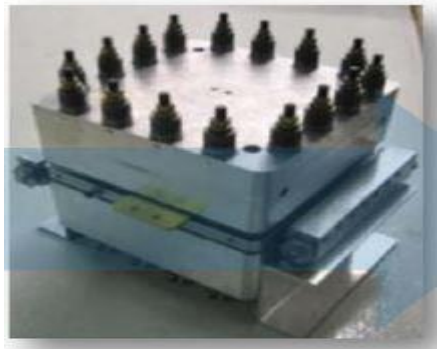
Proton Exchange Membrane Electrolyzer Architecture







From 50 Watt Stack → Up to 250 kW Stack

MW Scale PEM Electrolyzer Model

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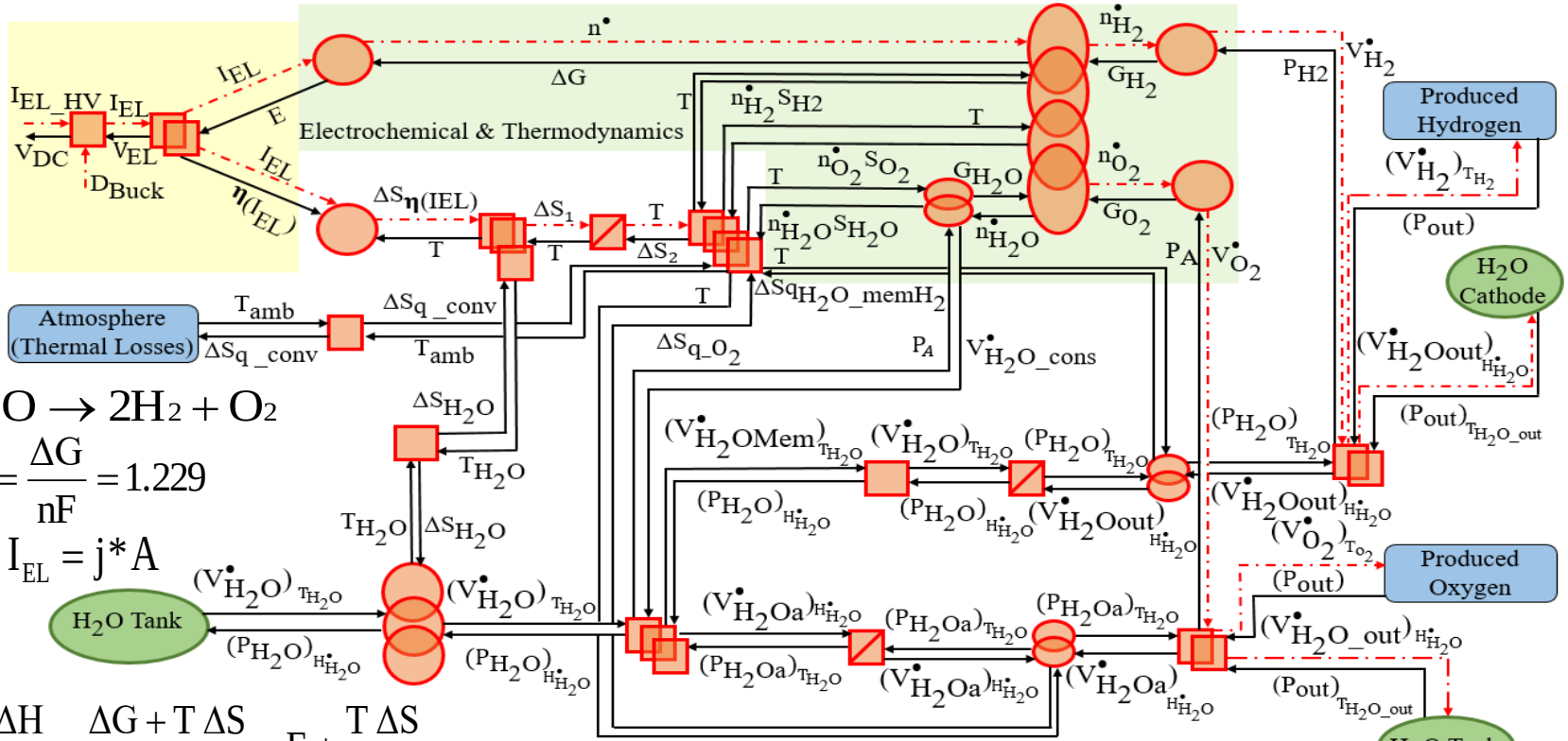
Simulink Model Based on Energetic Model Representation (EMR)



$$2H_2O \rightarrow 2H_2 + O_2$$

$$E_{ref} = \frac{\Delta G}{nF} = 1.229$$

$$I_{ST} = I_{EL} = j * A$$

$$V_{tn} = \frac{\Delta H}{nF} = \frac{\Delta G + T\Delta S}{nF} = E + \frac{T\Delta S}{nF}$$

$$V_{EL} = V_{tn} + \eta(I_{EL})$$

$$\varepsilon_{EL} = \frac{HHV * n^{\bullet}_{H_2}}{I_{EL} * V_{EL}} = \frac{HHV * I_E}{2 * F * I_{EL} * V_{EL}} = \frac{\frac{HHV}{2F}}{V_{EL}} = \frac{1.482}{V_{EL}}$$

$$n^{\bullet}_{H_2O\_ST} = n^{\bullet}_{H_2\_ST} = 2 * n^{\bullet}_{O_2\_ST} = \frac{I_{ST}}{2F} * \eta_F * N_{cell} = n^{\bullet}_i * N_{cell}$$

MW Scale PEM Electrolyzer Model

Reverse Engineering Requirements

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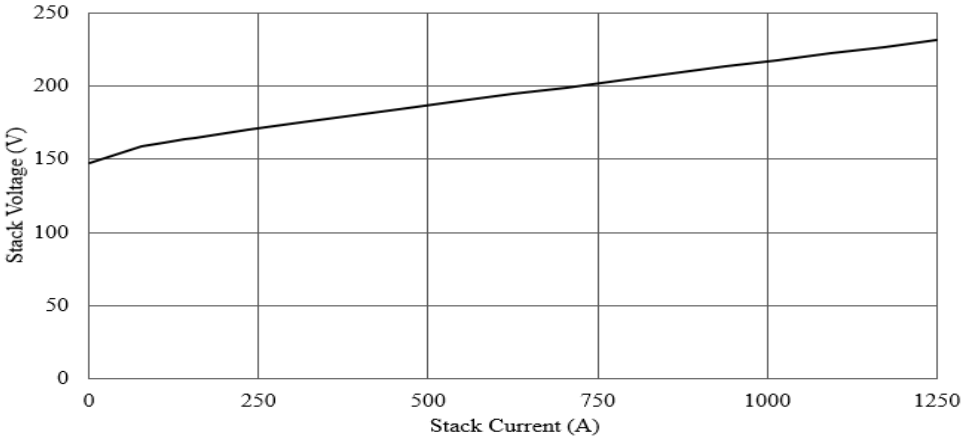
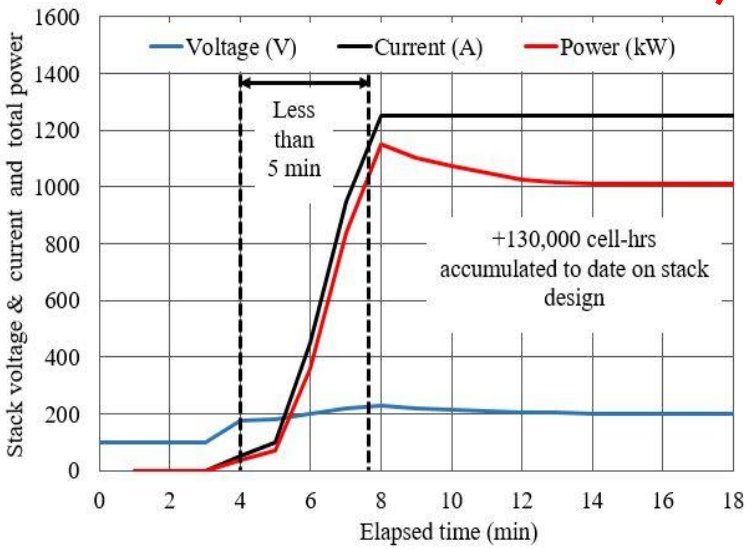
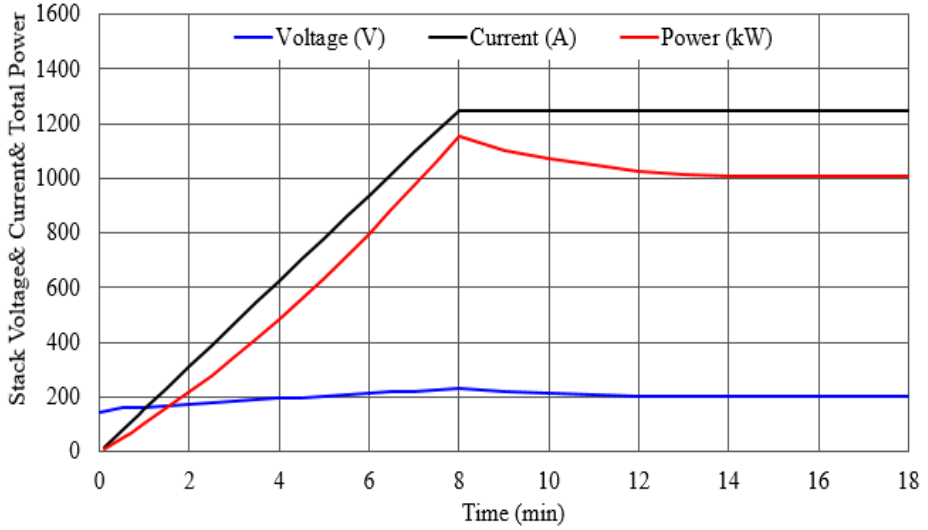
Polarization Curve
Current Density
Cell Area
Number of Cells

Deduced







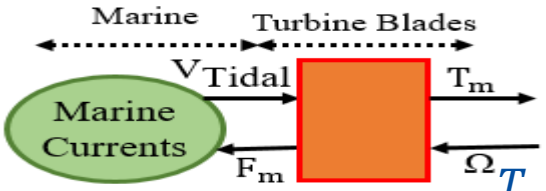
MW Scale PEM Electrolyzer Model

Simulink Model Parameters

Parameter	Small-scale Staxxx7-HTECH	Proton Onsite model
Power (kW)	0.05	250
MEA active area (cm^2)	16	650
Number of cells	7	100
Output pressure (bar)	1	30
Current density (A/cm^2)	0.25	1.9231
Anode exchange current density (A/cm^2)	$0.1548*10^{-2}$	$8*0.1548*10^{-2}$
Cathode exchange current density (A/cm^2)	$0.3539*10^{-1}$	$8*0.3539*10^{-1}$
Membrane conductivity (S/cm)	$0.9322*10^{-2}$	$8*0.9322*10^{-2}$
Anode charge transfer coefficient	0.7178	0.7178
Cathode charge transfer coefficient	0.6395	0.6395
Hydrogen production rate (Nm^3/h)	No details	50
Reactant water consumption rate (L/h)	No details	45

Tidal Turbine Modeling & Control

Tidal Turbine EMR



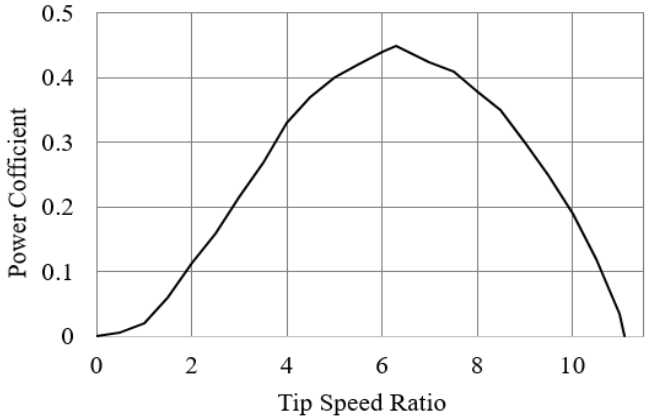
$$P_t = 0.5\ \rho\ A\ V^3$$

$$P_m = 0.5\ \rho\ A\ V^3\ C_P$$

$$\lambda = \frac{R\Omega}{V}$$

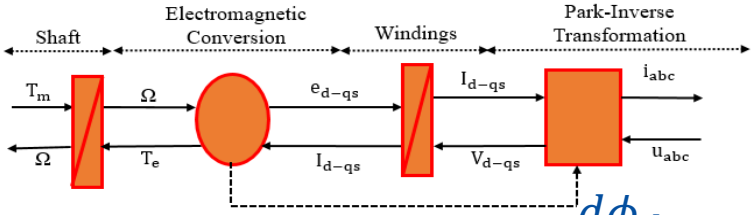
$$T_m - T_e = J\frac{d\Omega}{dt} + F\,\Omega$$

Direct Drive Mechanical Coupling



Tidal Turbine Power Coefficient-Tip Speed Ratio C/C's

PMSG EMR



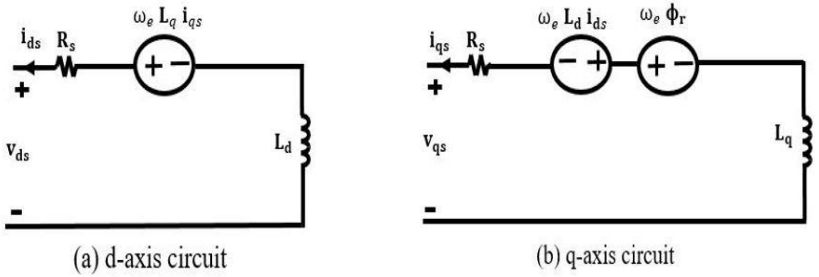
$$V_{ds} = -R_s i_{ds} - \omega_e \phi_{qs} + \frac{d\phi_{ds}}{dt}$$

$$V_{qs} = -R_s i_{qs} + \omega_e \phi_{ds} + \frac{d\phi_{qs}}{dt}$$

$$T_e = \frac{3\,P}{2}\left(i_{qs}\,\phi_{qs} - i_{ds}\,\phi_{ds}\right)$$

$$P_{Core} = P_{Fe0}\left(\frac{U_s}{U_0}\right)^{2.2}\left(\frac{f}{f_0}\right)^{-0.7}$$

$$P_{cu} = \frac{3}{2}\left(i_{ds}^2 + i_{qs}^2\right)R_S$$



d-q axes PMSG Equivalent Circuit

Tidal Turbine Modeling & Control

Machine Side Converter Control Strategies

Power Control Strategy

$$T_e = \frac{3}{2} P \Phi_r i_{qs}$$

$\Omega < \Omega_r$

$$T_{mopt} = \frac{P_m}{\Omega} = 0.5 \Pi \rho R^5 (6.3 * \frac{R}{V})^2 \frac{0.45}{6.3} = 4.45 \rho \frac{R^7}{V^2}$$

$\Omega > \Omega_r$

$$T_{mopt} = \frac{P_{mrated}}{\Omega} = \frac{3}{2} P \Phi_r i_{qs}$$

Flux Control Strategy

$\Omega < \Omega_r$

$i_d = 0$

Maximum T/A

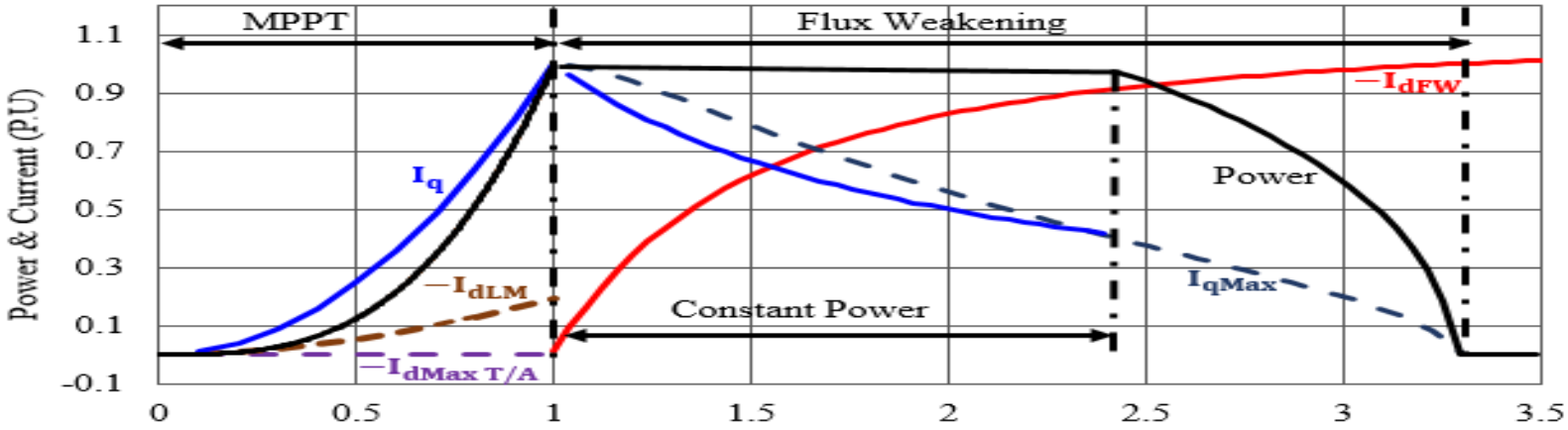
$\Omega > \Omega_r$

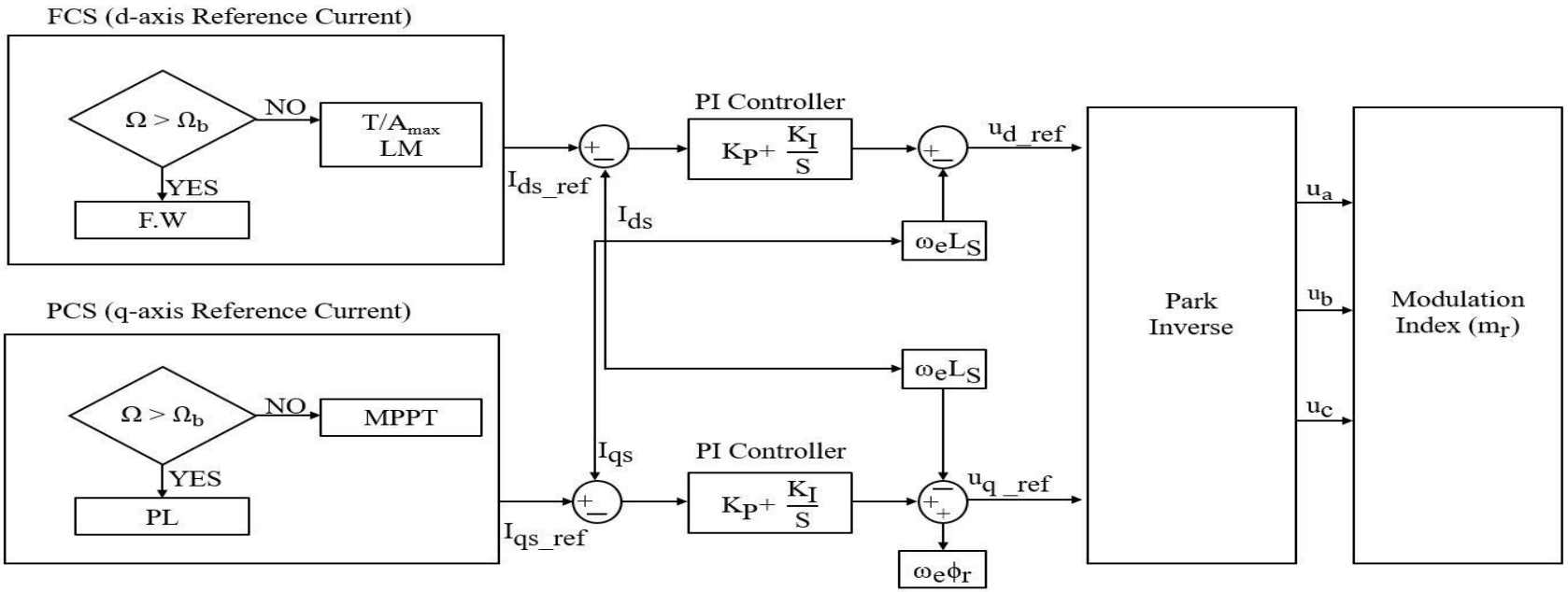
Flux Weakening

$$i_{dsrefLM} = \frac{\omega_e^2 L_S (R_s + R_c) \lambda_r}{R_s R_c^2 + \omega_e^2 L_S^2 (R_s + R_c)}$$

Loss Minimization

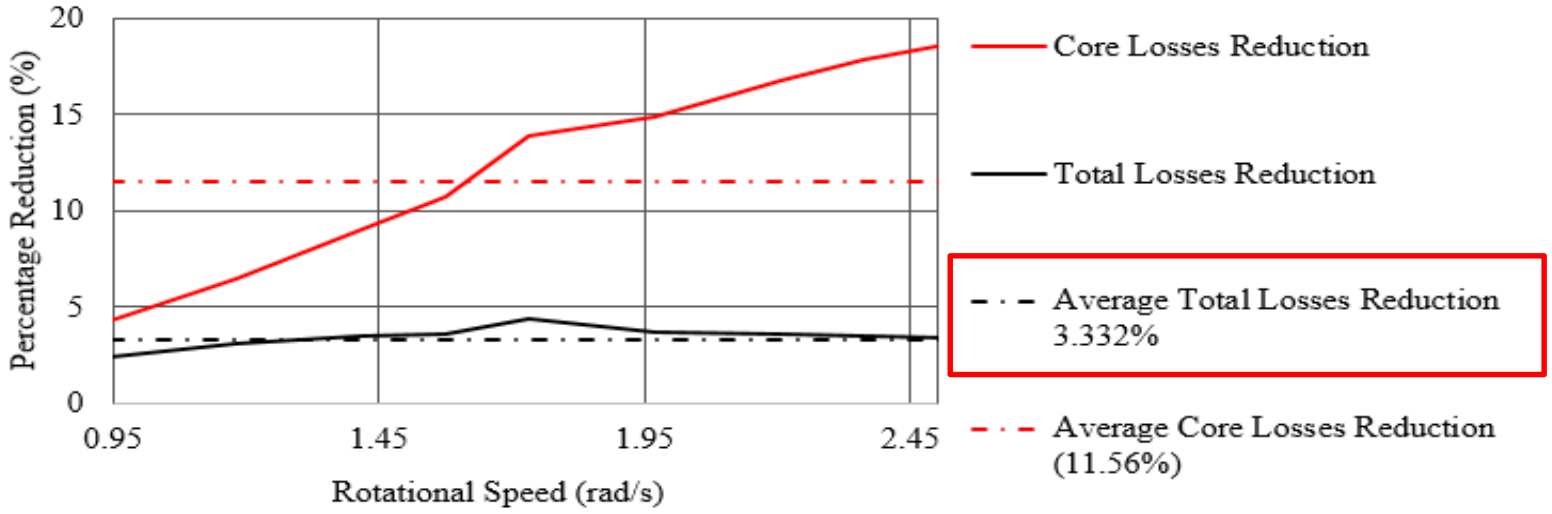
Tidal Turbine Modeling & Control





Results

PMSG Loss Minimization Control Strategy



3.33% reduction [1.245 MW MCT works annually 7864 hours in MPPT to produce 656 MWh] = 4000 kWh (one household average consumption)

Or equals

100 kg of Hydrogen production per year considering the HHV and without considering electrolyzer system efficiency

Conclusion

This research was partially supported by Interreg North-West Europe Interreg NWE, ITEG (Integrating Tidal Energy into the European Grid) project, Grant number NWE 613.

The main objective of ITEG project is the investigation of the renewable energy based hydrogen production (mainly marine current energy) in all-in one-solution for forcing the remote areas weak grid.

This research presents an MW PEM electrolyzer model integrated with one tidal converter with designing the control system for maximizing the generated hydrogen.

As a case study, the proposed control system provides surplus hydrogen production of almost 100 kg from the considered 1,25 MW tidal converter. With considering the electrolyzer efficiency in the range of 50% to 60%, the increase of hydrogen production will be almost 50 kg from.

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