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# Enhanced Efficiency Wind Energy Conversion System for Ship Propulsion Applications

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E. Tsioumas, N. Jabbour, and C. Mademlis
School of Electrical and Computer Engineering
Aristotle University of Thessaloniki, Greece

EMLab

ARISTOTLE UNIVERSITY OF THESSALONIKI

# OUTLINE OF THE PRESENTATION

- Overview of the efficiency problem in wind energy conversion system (WECS) for ship applications
- Aim of the paper
- Configuration of a WECS with a squirrel cage induction generator (SCIG)
- Proposed control strategy
- Simulation results
- Conclusions

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## *Advantages*

- ✓ ***Renewable and sustainable*** and so, will never run out
- ✓ ***Environmentally friendly*** (little to no pollution after manufacturing and installation of a wind turbine)
- ✓ ***Reduces fossil fuel*** consumption and other alternatives (e.g. coal, oil, gas) for the total generating electric power
- ✓ ***Wind energy is free*** and thus, low running costs
- ✓ ***Small footprint*** (the area around the base of a turbine can be used for other purposes such as agriculture)
- ✓ ***Remote power solution*** (e.g. small grid-off villages, remote search stations, etc.)
- ✓ ***Huge energy potential***
- ✓ ***Job creation***

## *Disadvantages*

- ❖ ***Wind fluctuates*** and thus, it is not a constant energy source.
- ❖ ***Installation is expensive***
- ❖ ***Noise pollution***
- ❖ ***Threat to wildlife*** (e.g. birds and bats)
- ❖ ***Visual pollution***, although this trends coms to personal opinion

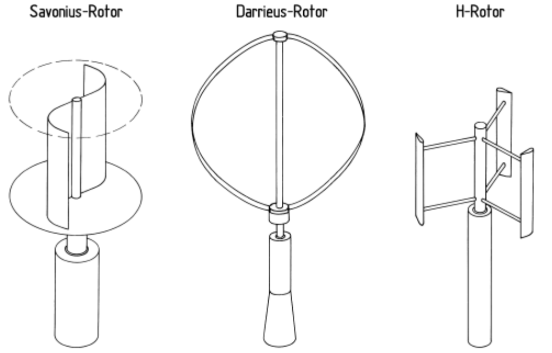
# Overview of the efficiency problem in wind energy conversion system (WECS) for ship applications

Wind energy
for ship applications

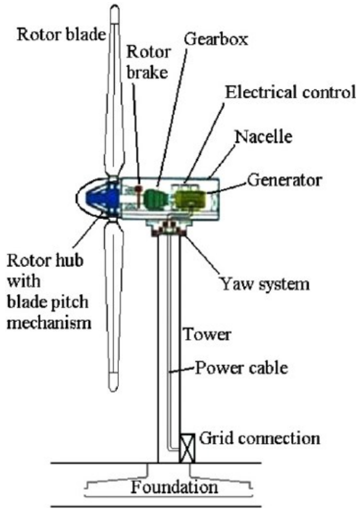



# OVERVIEW OF THE EFFICIENCY PROBLEM IN WIND ENERGY CONVERSION SYSTEM (WECS) FOR SHIP APPLICATIONS

*VAWT*

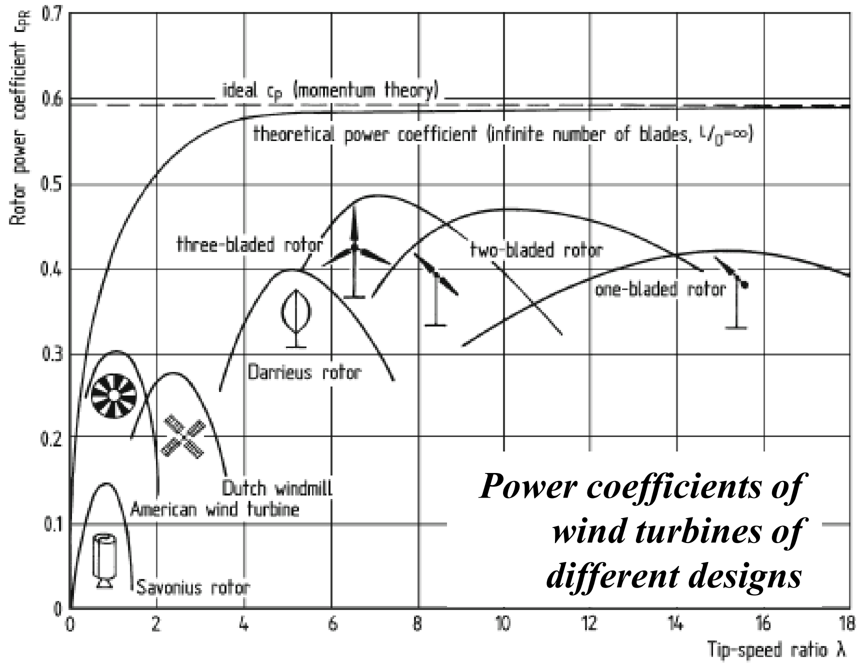



*HAWT*

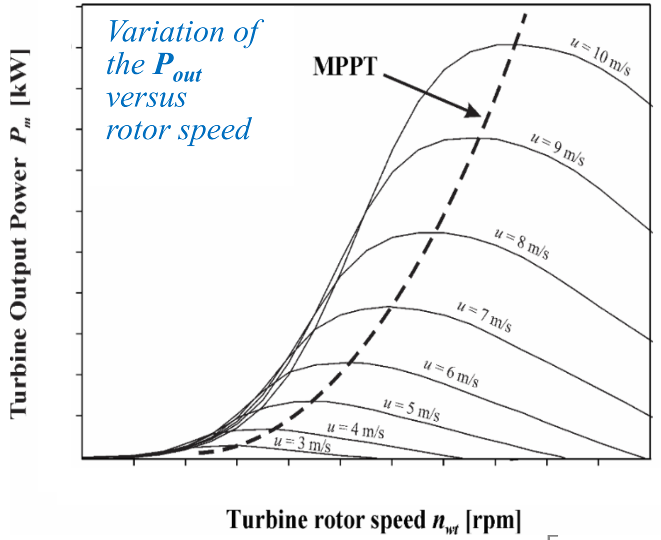



***Power aerodynamic coefficient***

$$C_p = \frac{P_{wt}}{P_w}$$




***Power coefficients of wind turbines of different designs***



# Overview of the efficiency problem in wind energy conversion system (WECS) for ship applications

There are many ***different types of electrical generators*** that could be used in wind turbines.

***Squirrel cage induction generators (SCIG)***

robust and low cost

**however...**

need reactive power for the proper operation and
all the generated electric power should be controlled

***Permanent magnet synchronous generators (PMSG)***

highly efficient and no need of gear-box

**however...**

expensive (due to rare-earth magnets), heavier and
all the generated electric power should be controlled

***Doubly fed induction generators (DFIG)***

flexible regulation of active and reactive power,
low requirements for converter capacity

**however...**

lower efficiency compared to PMSG and
difficult to apply mag.-flux weakening control for efficiency improvement

Regulations in Maritime sector

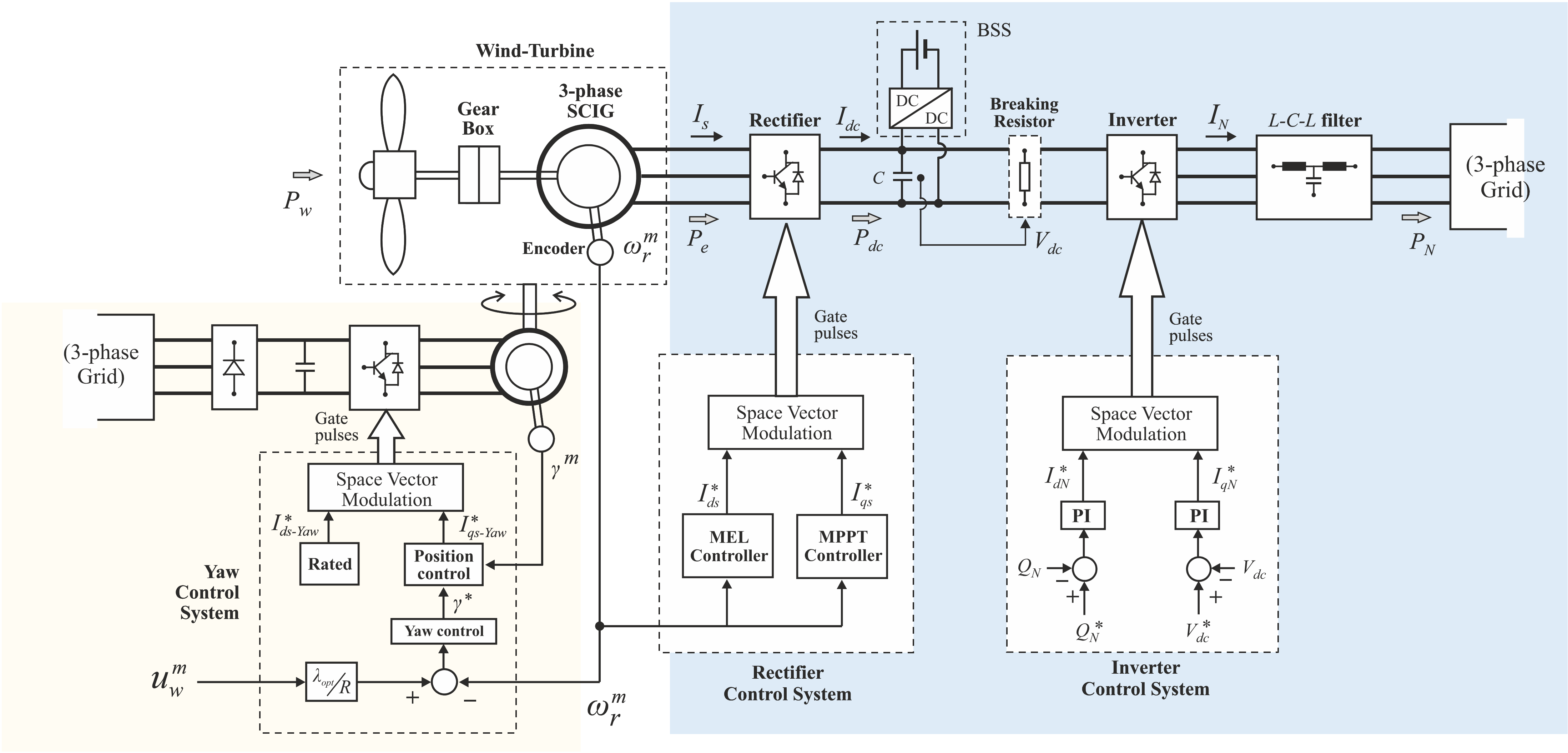
- *International Maritime Organization (IMO)* contributes to the global effort for protection of the environment and adopted several measures under the:
  - *International Convention for the Prevention of Pollution from Ships* (MARPOL),
  - in accordance with the *ship's Energy Efficiency Design Index* (EEDI) and
  - the *Ships' Energy Efficiency Management Plan* (SEEMP).

- ***IMO strategy***:
  - greenhouse gas (GHG) decrease in international shipping aims to at least 40% reduction of CO2 emissions per transport work by 2030.
  - adoption of near-zero or zero GHG emission technologies of energy sources for the 10% of the energy needed in international shipping by 2030.

# II. Aim of the Paper

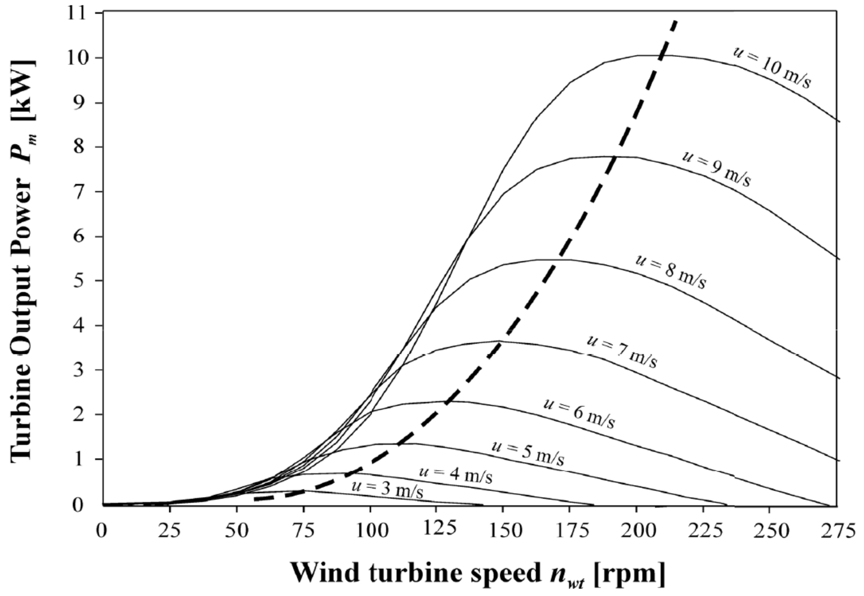
- ***An optimal efficiency control scheme for WECS with SCIG for ships' applications*** by providing minimum power loss and maximum power tracking by the incident wind.
- The proposed integrated control scheme combines both ***SCIG and yaw control*** (for the case of VAWTs).
- The system is ***supported by a battery storage system (BSS)*** for temporary storage of the excess energy produced by the wind turbine that cannot be absorbed by the ship propulsion system.
- The operating improvements and the effectiveness of the suggested control system have been ***verified with a simulation analysis*** in MATLAB/Simulink

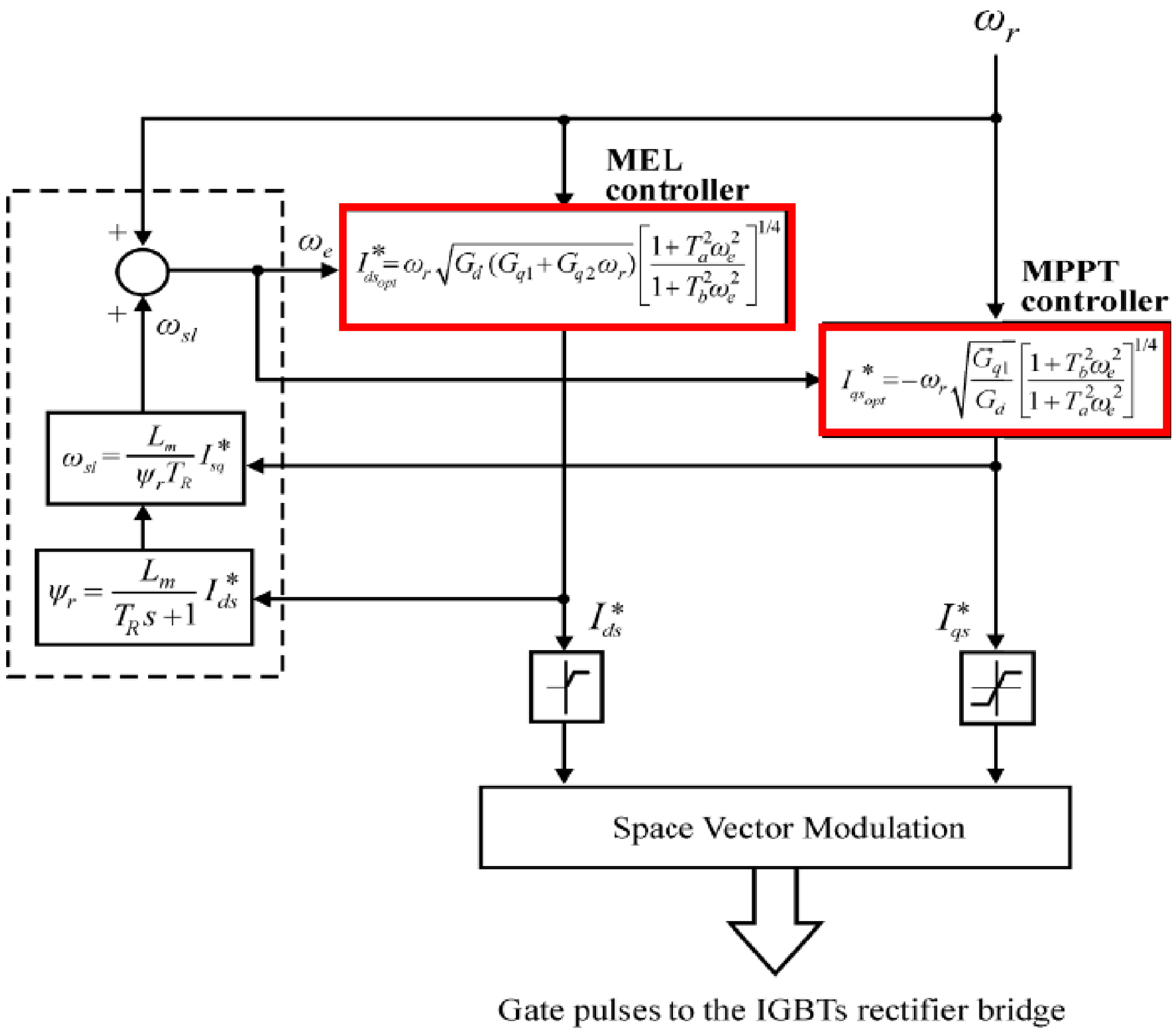
# III. CONFIGURATION OF A WECS WITH A SQUIRREL CAGE INDUCTION GENERATOR (SCIG)



# IV. Proposed Control Strategy

## (Optimal Efficiency of the SCIG)



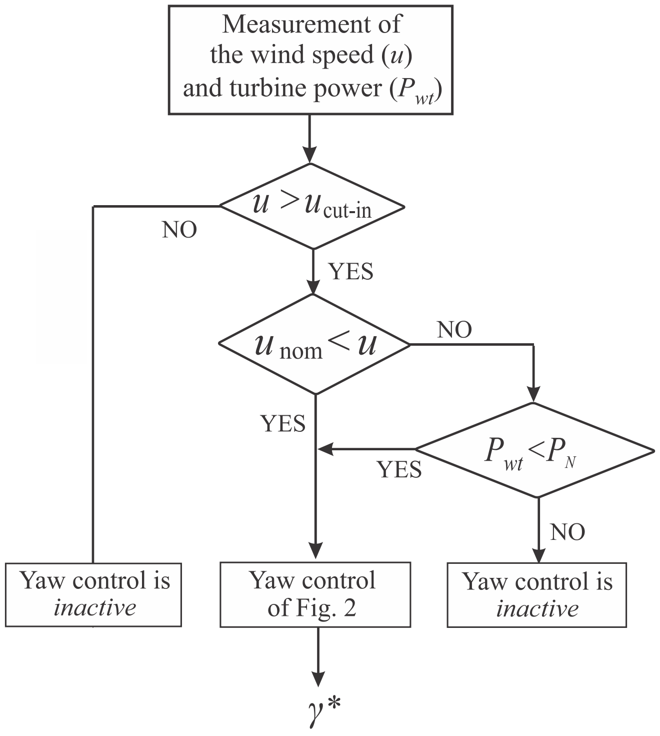



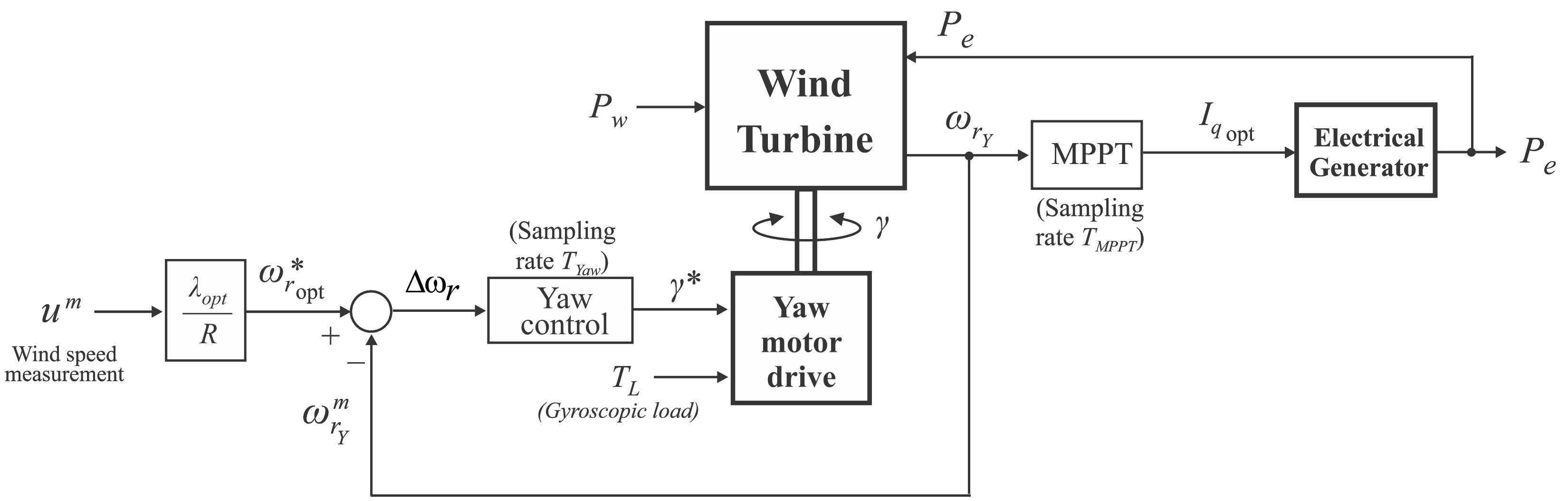
# IV. PROPOSED CONTROL STRATEGY

## (YAW CONTROL)

$$C_p(\lambda,\beta,\gamma) = C_p(\lambda,\beta)\cos^h\gamma$$

$$\cos\gamma = \left(1 - \frac{\omega_{r_{opt}} - \omega_{r_Y}}{\omega_{r_{opt}}}\right)^{3/h}$$



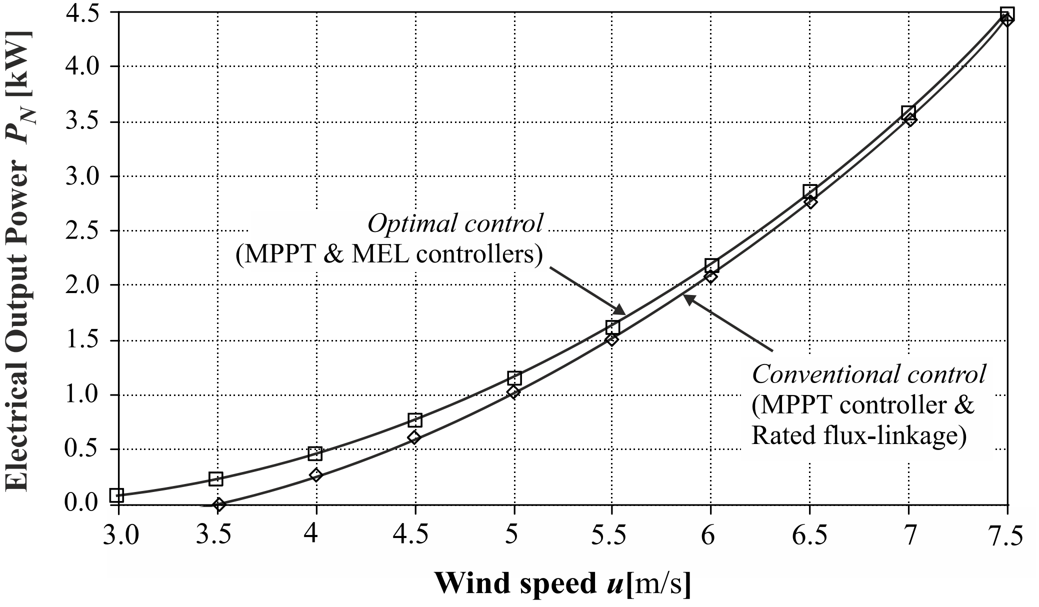
# V. Simulation Results

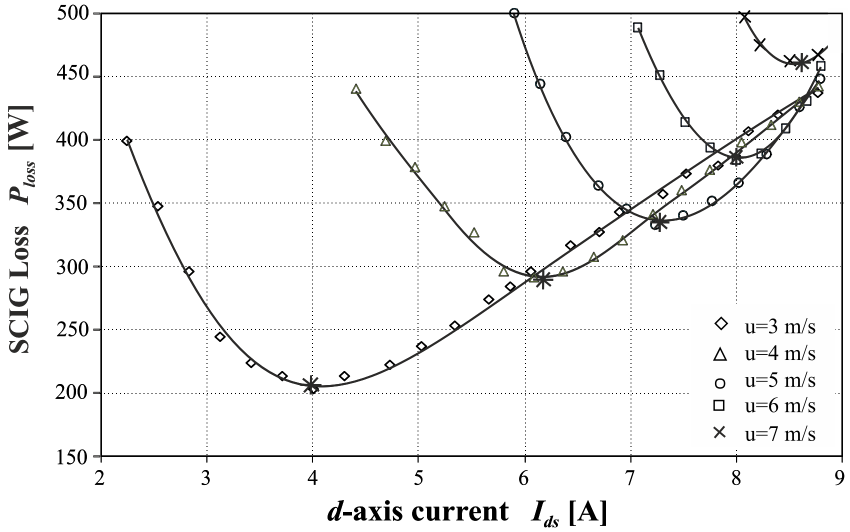
**TABLE 1**

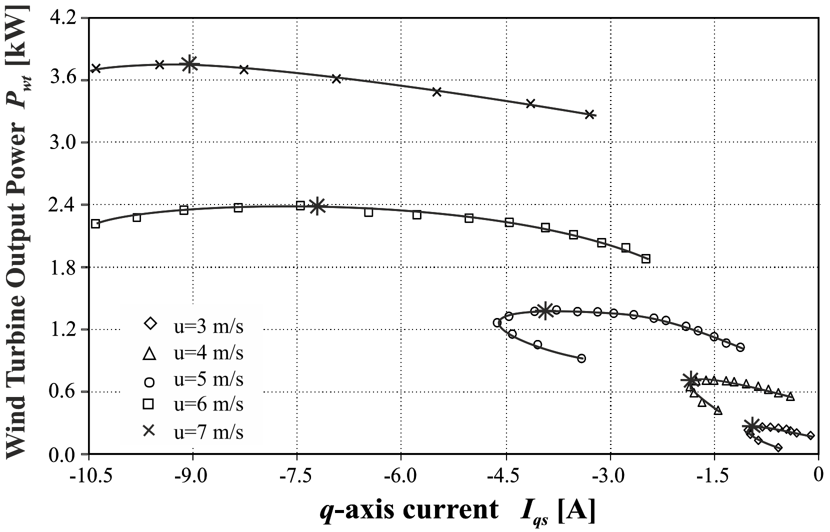
3-PHASE, 10-kW, SCIG AND OPTIMAL CONTROLLER PARAMETERS

| | | |
|---|---|---|
| $V_s$ = 400 V (rms) | | $I_s$ = 21 A (rms) |
| $f_e$ = 50 Hz | | $2p$ = 4 (number of poles) |
| $R_s$ = 0.7 Ω | | $R_r$ = 1 Ω |
| $L_m$ = 0.2 H | $L_{ls}$ = 0.01 H | $L_{lr}$ = 0.01 H |
| $G_d$ = 1.558 | $G_{q1}$ = 2.23·10$^{-2}$ | $G_{q2}$ = 2.9·10$^{-4}$ |
| $T_a$ = 2.51·10$^{-3}$ | | $T_b$ = 1.82·10$^{-2}$ |

# V. Simulation Results



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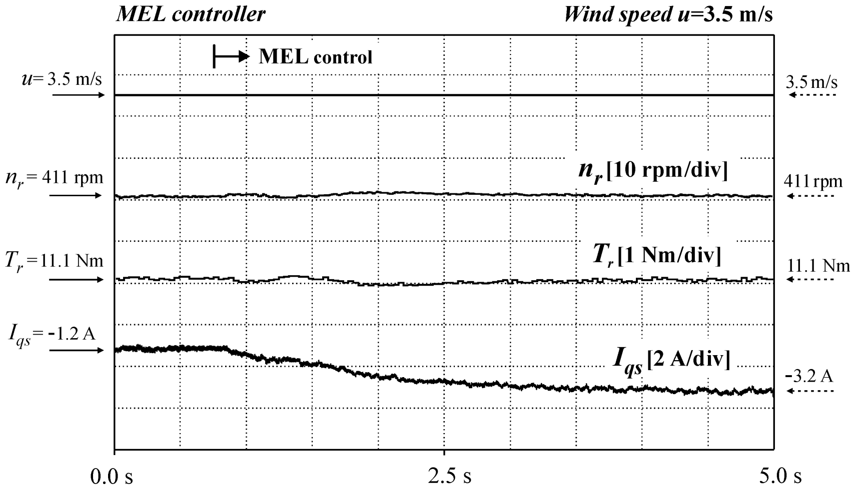


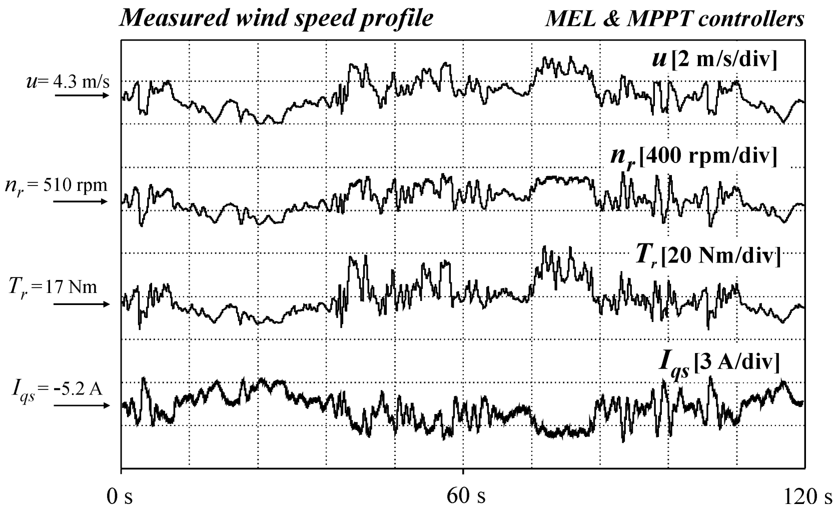


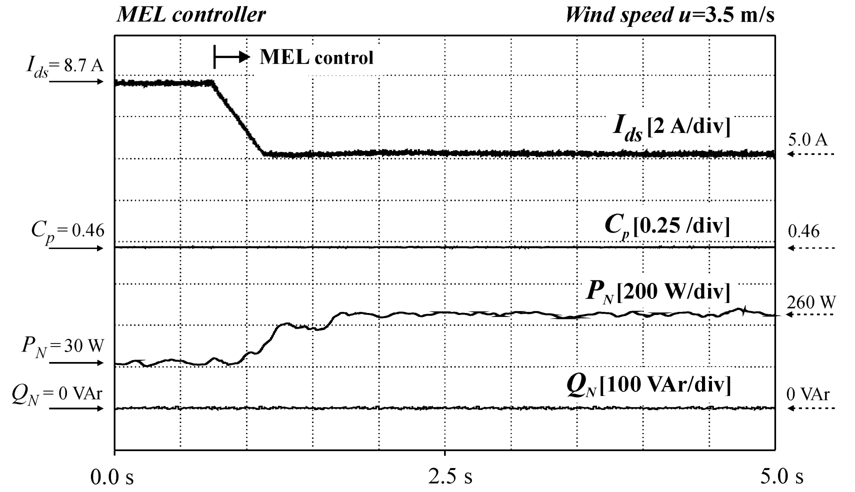


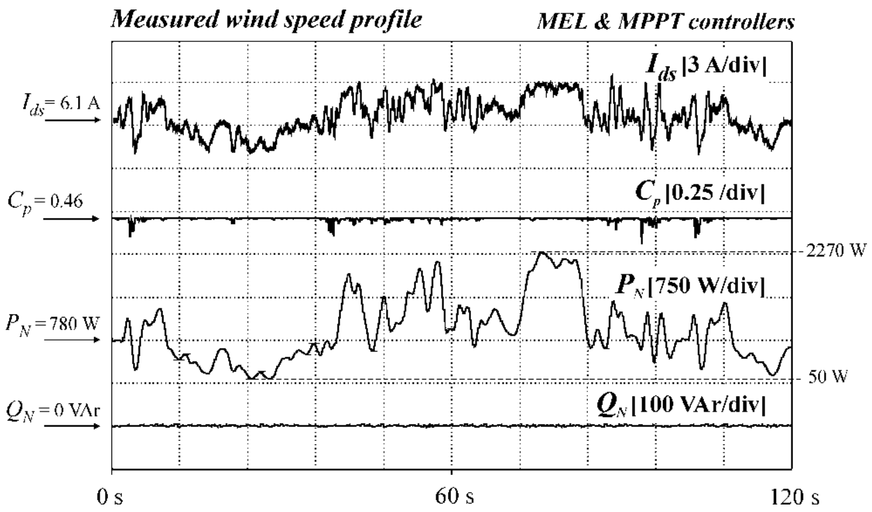

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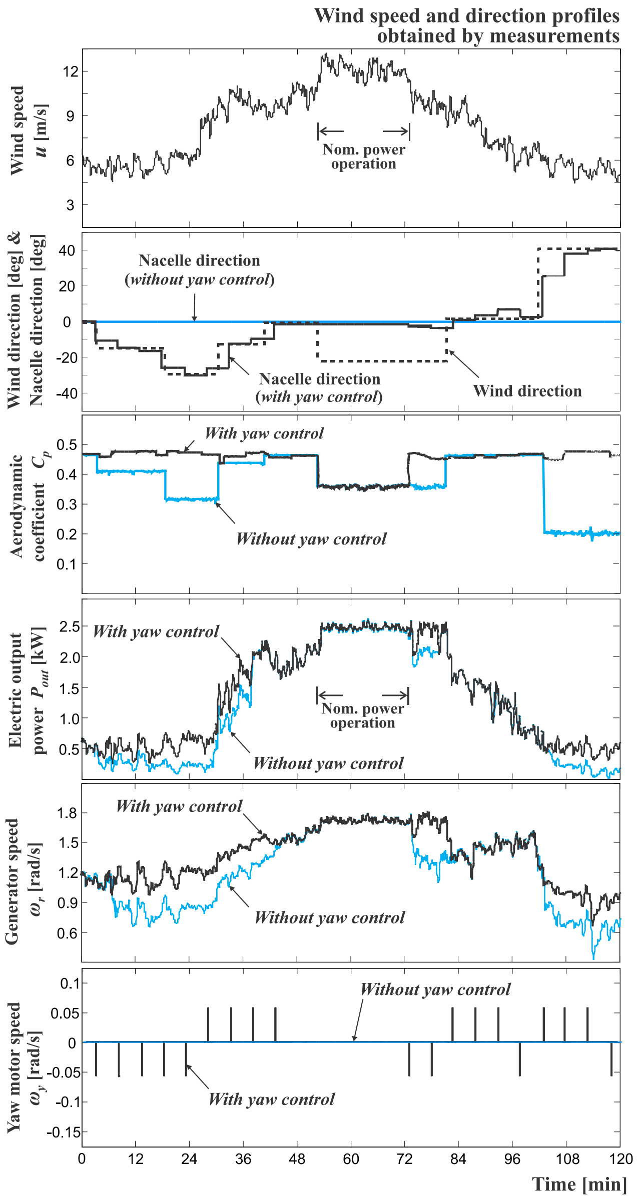

# CONCLUSIONS

- ***A combined scheme of a WECS with a SCIG and a BSS*** has been utilized. The proposed control system ***can enhance the efficiency of the WECS*** by minimizing the electric loss of the generator and attaining maximum energy harvesting (MPTT) by the wind.

- ***A yaw control system*** has been proposed that can cooperate with the optimal efficiency and MPPT controllers to correctly align the wind turbine to the wind direction.

- ***No additional hardware is required*** for the implementation of the system.

- ***The BSS provides smooth power and energy performance of the ship's electric microgrid*** by absorbing any potential fluctuations of electric energy generated by the wind turbine and electric loads on board.

- The effectiveness of the suggested combined scheme of WECS-BSS with yaw control for ship applications has been ***validated through simulations***.

*Patented:*
***EP 2013/0386032***
*'Method for efficiency optimization of a wind generator by controlling the electrical generator and system therefor'.*