



Hamed Aly

# Offshore Wind and Tidal Current Energy Resources

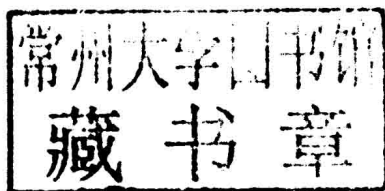
Forecasting, Modeling, and Control



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DEDICATION PAGE

*To soul of those who loved me more than themselves, to my parents.*



## **LIST OF ABBREVIATIONS AND SYMBOLS USED**

### **List of Abbreviations (in the order of appearance in the work)**

|        |                                                        |
|--------|--------------------------------------------------------|
| DFIG   | Doubly Fed Induction Generator                         |
| DDPMSG | Direct Drive Permanent Magnet Synchronous              |
| ANN    | Artificial Neural Network                              |
| FLSM   | Fourier Series Model based on the Least Squares Method |
| PI     | Proportional Integral                                  |
| R.I.   | Research Institute                                     |
| IEA    | International Energy Agency                            |
| FORCE  | Fundy Ocean Research Centre for Energy                 |
| EU     | The European Union                                     |
| UK     | United Kingdom                                         |
| MW     | Mega Watt                                              |
| WWEA   | World Wide Energy Association                          |
| BC     | British Columbia                                       |
| AB     | Alberta                                                |
| SK     | Saskatchewan                                           |
| MB     | Manitoba                                               |
| ON     | Ontario                                                |
| QC     | Quebec                                                 |
| NB     | New Brunswick                                          |
| NS     | Nova Scotia                                            |
| FSIG   | Fixed Speed Induction Generator                        |
| SSC    | Supply Side Converter                                  |
| GSC    | Grid Side Converter                                    |
| RSC    | Rotor Side Converter                                   |
| AVR    | Automatic Voltage Regulator                            |
| DC     | Direct Current                                         |
| IGBT   | Insulated Gate Bipolar Transistor                      |

|         |                                                        |
|---------|--------------------------------------------------------|
| STATCOM | Static Synchronous Compensator                         |
| FMAC    | Flux Magnitude Angle Controller                        |
| PSS     | Power System Stabilizer                                |
| MCU     | Master Control Unit                                    |
| TSO     | Transimission System Operator                          |
| UCS     | Single Unit Control                                    |
| TED     | Tidal Energy Devices                                   |
| MCT     | Marine Current Turbines                                |
| UEK     | Underwater Electric Kite                               |
| RTT     | Rotech Tidal Turbine                                   |
| ANN     | Artificial Neural Network                              |
| FLSM    | Fourier Series model based on the Least Squares Method |
| PBN     | Back Propagation Neural Network                        |
| RBF     | Radial Basis Function                                  |
| MRA     | multi-resolution analysis                              |
| GA      | Genetic Algorithms                                     |
| EOF     | Empirical Orthogonal Function                          |
| PC      | Principal Components                                   |
| MLP     | Multi Layer Perceptron                                 |
| PCA     | Principal Component Analysis                           |
| SOFM    | Self Organizing Feature Map                            |
| RBF     | Radial Basis Function                                  |
| SLP     | Single Layer Perceptron                                |
| OBD     | Optimal Brain Damage                                   |
| P E     | Percentage of Error                                    |

**List of Symbols (in the order of appearance in the work)**

|            |                                                    |
|------------|----------------------------------------------------|
| $v_w$      | Wind speed signals model                           |
| $v_{mw}$   | Mean wind speed                                    |
| $v_{rw}$   | Wind speed ramp                                    |
| $v_{gw}$   | Wind speed gust                                    |
| $v_{tw}$   | Turbulence                                         |
| $A_r$      | Amplitude of the wind speed ramp                   |
| $T_{sr}$   | Starting time                                      |
| $T_{er}$   | Ending time                                        |
| $v_{gw}$   | Wind speed gust                                    |
| $C_p$      | Wind power coefficient                             |
| $\lambda$  | Tip speed ratio                                    |
| $B$        | Pitch angle                                        |
| $R$        | The blade length in m                              |
| $\rho$     | The density of the air                             |
| $\omega_t$ | The wind turbine rotational speed in rad/sec       |
| $C_f$      | The wind turbine blade design constant             |
| $P_w$      | Power extracted from the wind                      |
| $T_m$      | Mechanical torque applied to the turbine           |
| $v_m$      | The turbine speed at hub height upstream the rotor |
| $D_t$      | The turbine self-damping                           |
| $D_g$      | The generator self damping                         |
| $D_m$      | The mutual damping                                 |
| $H_t$      | The turbine inertia constant                       |
| $H_g$      | The generator inertia constants                    |
| $K_s$      | The shaft stiffness                                |
| $\omega_t$ | The turbine rotor speed                            |
| $\omega_g$ | The generator rotor speed                          |
| $\Theta_t$ | The turbine rotor angle                            |
| $\Theta_g$ | The generator rotor angles                         |

|                                |                                                                                                                     |
|--------------------------------|---------------------------------------------------------------------------------------------------------------------|
| $H_m$                          | The lumped inertia constant                                                                                         |
| $\omega_m$                     | The rotational speed of the lumped system                                                                           |
| $D_m$                          | The damping of the lumped system                                                                                    |
| $Y_j(t)$                       | Quantity computed by the first hidden neurons                                                                       |
| $Y_k(t)$                       | Quantity computed by the second hidden neurons                                                                      |
| $O_r(t)$                       | Network output                                                                                                      |
| $X$ & $Z$                      | Number of input and output neurons                                                                                  |
| $H_1$ & $H_2$                  | Number of first and second hidden neurons                                                                           |
| $W_{ij}$ , $W_{jk}$ & $W_{kr}$ | Adjustable weights between input and first hidden layer, the first and second layer and the second and output layer |
| $b_i$                          | Number of biases                                                                                                    |
| $f$                            | Transfer function                                                                                                   |
| $E$                            | Error                                                                                                               |
| $\eta$                         | The learning rate                                                                                                   |
| $\alpha$                       | The momentum                                                                                                        |
| $V_{tide}$                     | Tidal current speeds.                                                                                               |
| $V_{nt}$                       | Neap tide speed.                                                                                                    |
| $V_{st}$                       | Spring tide speed.                                                                                                  |
| $C_s$                          | Constant and equals 95 for spring, 45 for neap tide.                                                                |
| $P_{ts}$                       | Tidal in-stream power.                                                                                              |
| $\rho$                         | Density of the water (1025 kg/m <sup>3</sup> )                                                                      |
| $A$                            | Cross-sectional area perpendicular to the flow direction.                                                           |
| $T_m$                          | Mechanical torque applied to the turbine.                                                                           |
| $A$                            | Cross-sectional area perpendicular to the flow direction.                                                           |
| $C_p$                          | Marine turbine blade design constant in the range of 0.35-0.5.                                                      |
| $\omega_s, \omega_r, \omega_t$ | Stator, rotor electrical angular velocities, and turbine speed at hub height upstream the rotor.                    |
| $T_e$                          | Electrical torque of the generator.                                                                                 |
| $D_s$                          | Shaft stiffness damping.                                                                                            |
| $H_t, H_g$                     | Turbine and generator inertia constants.                                                                            |

|                          |                                                                                            |
|--------------------------|--------------------------------------------------------------------------------------------|
| $K_s$                    | Shaft stiffness coefficient.                                                               |
| $\Theta_t, \Theta_r$     | Turbine and generator rotor angles.                                                        |
| $B$                      | Tidal turbine pitch angle.                                                                 |
| $S$                      | Rotor slip.                                                                                |
| $d, q$                   | Indices for the direct and quadrature axis components.                                     |
| $s, r$                   | Indices of the stator and the rotor.                                                       |
| $v, R, i, \psi$          | Voltage, resistance, current, and flux linkage of the generator.                           |
| $K_{pt}, K_{it}$         | Coefficients for the proportional-integral controller of the pitch controller.             |
| $P_g, P_{DC}$            | Active power of the AC terminal at the grid side converter and DC link power respectively. |
| $v_{Dg}, v_{Qg}$         | D and Q axis voltages of the grid side converter.                                          |
| $i_{Dg}, i_{Qg}$         | D and Q axis currents of the grid side converter.                                          |
| $C$                      | Capacitance of the capacitor.                                                              |
| $v_{DC}, i_{DC}$         | Voltage and current of the capacitor.                                                      |
| $K_{p1}, K_{p2}, K_{p3}$ | Proportional controller constants for the generator side converter controller              |
| $K_{i1}, K_{i2}, K_{i3}$ | Integral controller constants for the generator side converter controller.                 |
| $i_{Dg}, i_{Qg}$         | D and Q axis grid currents.                                                                |
| $v_{Dg}, v_{Qg}$         | D and Q axis grid voltages.                                                                |
| $K_{p4}, K_{p5}, K_{p6}$ | Proportional controller constants for the grid side converter.                             |
| $K_{i4}, K_{i5}, K_{i6}$ | Integral controller constants for the grid side converter.                                 |
| $X_c$                    | Grid side smoothing reactance.                                                             |
| $\dot{x}$                | State variable.                                                                            |

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