“ DESIGN AND DEVELOPMENT OF A MARINE CURRENT ENERGY CONVERSION SYSTEM USING HYBRID VERTICAL AXIS TURBINE ”

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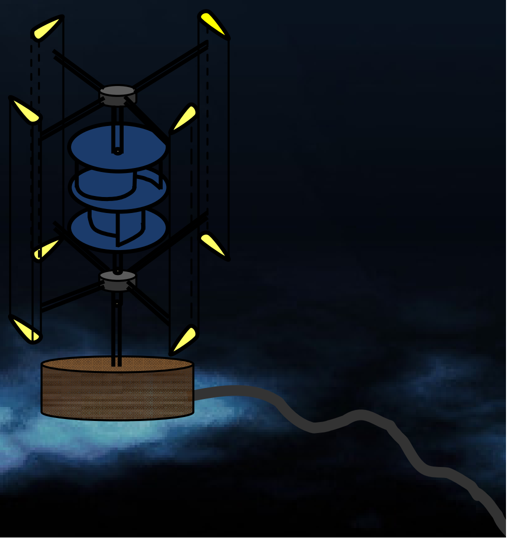


Agenda

- Ocean Currents
- Marine Current Energy Conversion System
- Thesis Objective
- Prototype Design
- Flume Tank Test and Test Results
- Experimental Energy Conversion System
- Conclusions

Ocean/Marine Currents

Horizontal movement of the Ocean water known as Ocean currents.

Mainly three types-

I. Tidal Currents

II. Wind driven Currents

III. Gradient (Density) Currents

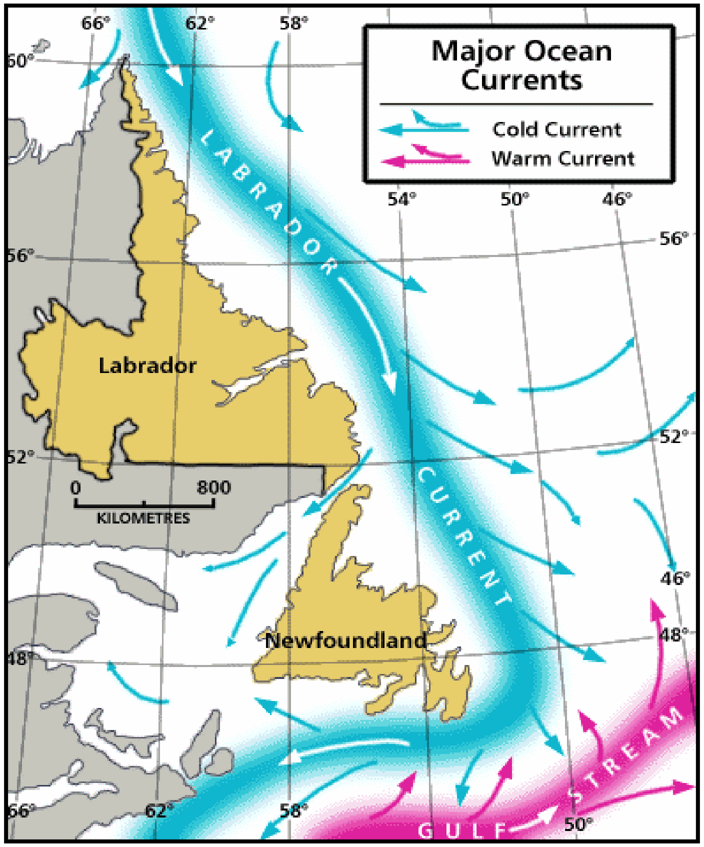


Fig: Labrador Current

Estimated total power = 5,000 GW

Power density may be up to 15kW/m^2

Tidal Currents

- **Vertical rise and fall of the water known as Tides**
- **Due to the gravitational attraction of the moon and sun**
- **Tidal Cycle of 12.5 Hours**

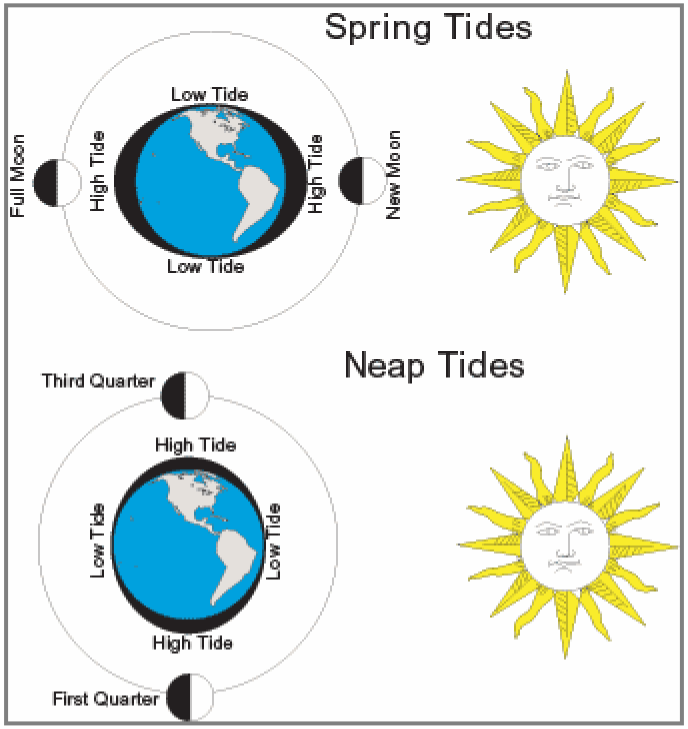
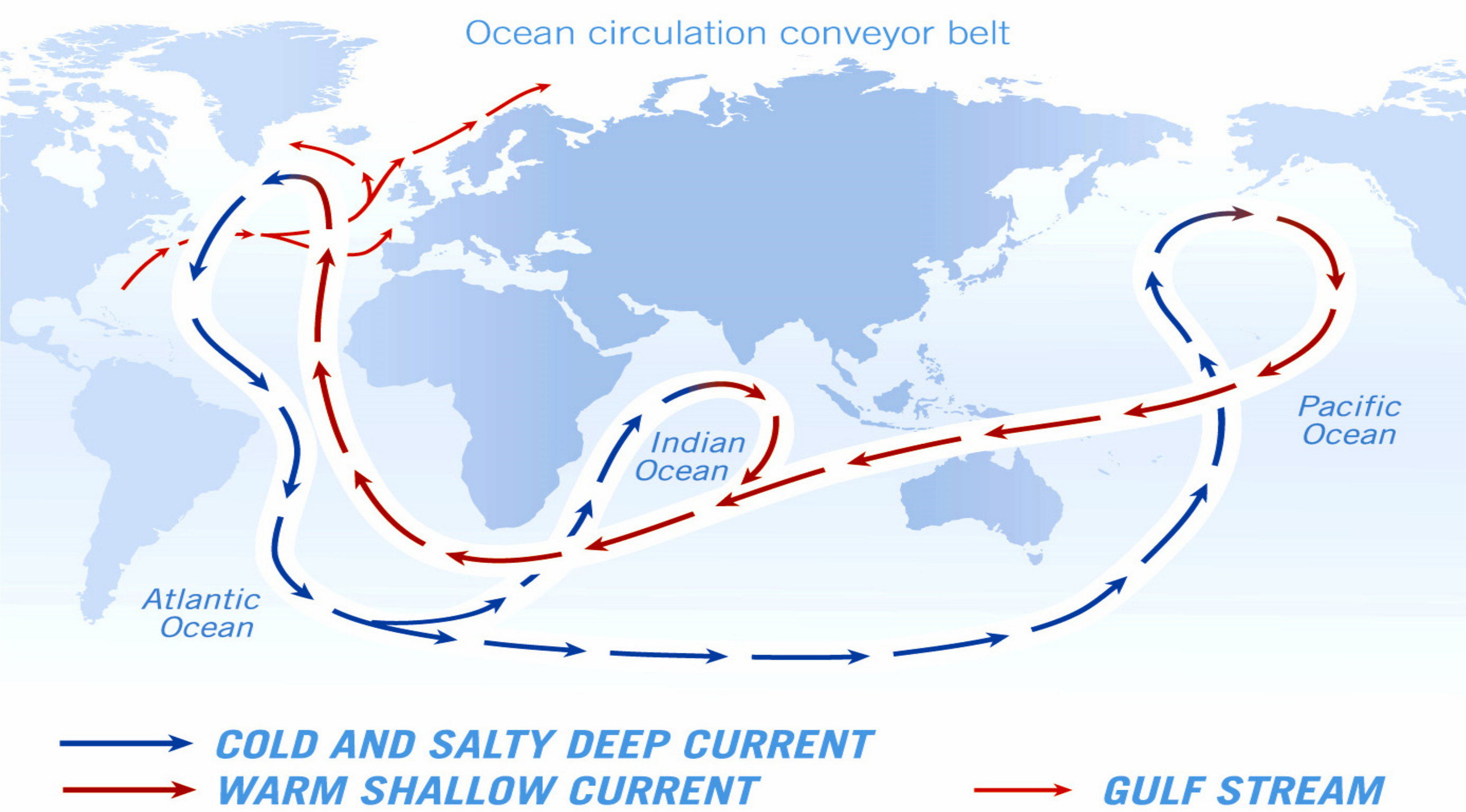


Fig: Tides (due to Gravitational Attraction)

Gulf Stream +THC or Great Conveyor Belt



The ocean circulation conveyor belt plays a key role in the climate of the Earth because of the transport of energy (heat) and matter.

North Atlantic current (Near St. John's)

Water Depth (m)	Average Water Flow (m/s)
20	0.146
45	0.132
80	0.112
Near Bottom	0.07

Table: Ocean Current Speeds (for different depths) at different areas of St. John's, NL

Marine Current Energy Conversion System

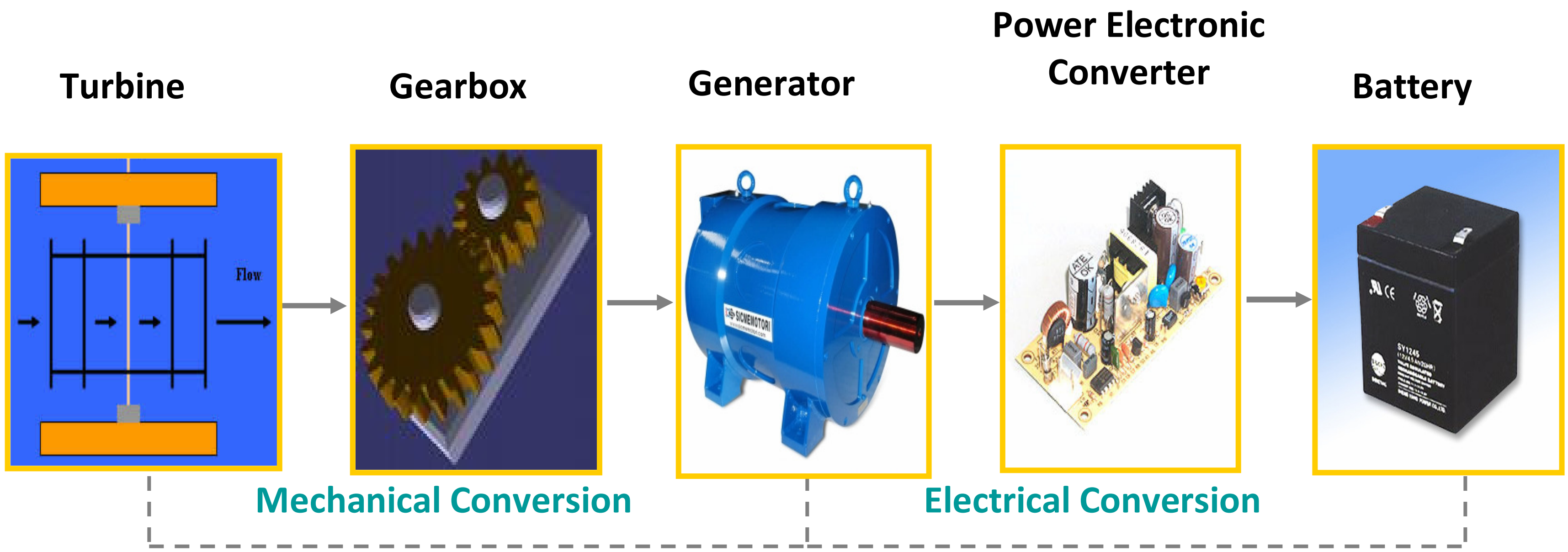


Figure: Marine Current Energy Conversion System (MCECS)

Thesis Objective

(As a part of ONSFI Project)

- **Design and Development of a low cut-in speed turbine for SEAformatics pods.**
- **System testing in a deep sea condition.**
- **Design and Development of Signal Condition circuits for the generated power.**
- **Maximum Power Point Tracker development for the designed conversion system.**

Ocean Current Turbines

Types of Turbine:

(According to OREG)

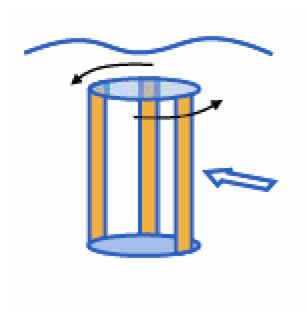


Fig. I: Vertical Axis

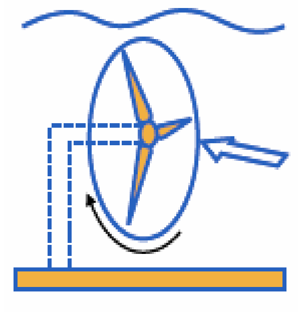


Fig. II: Horizontal Axis

I. **Vertical Axis Turbines**

II. **Horizontal Axis Turbines**

III. **Reciprocating Hydrofoils**

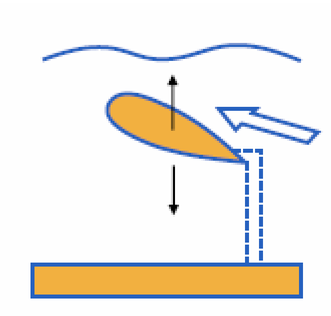


Fig. III: Reciprocating Hydrofoils

Commercial Application

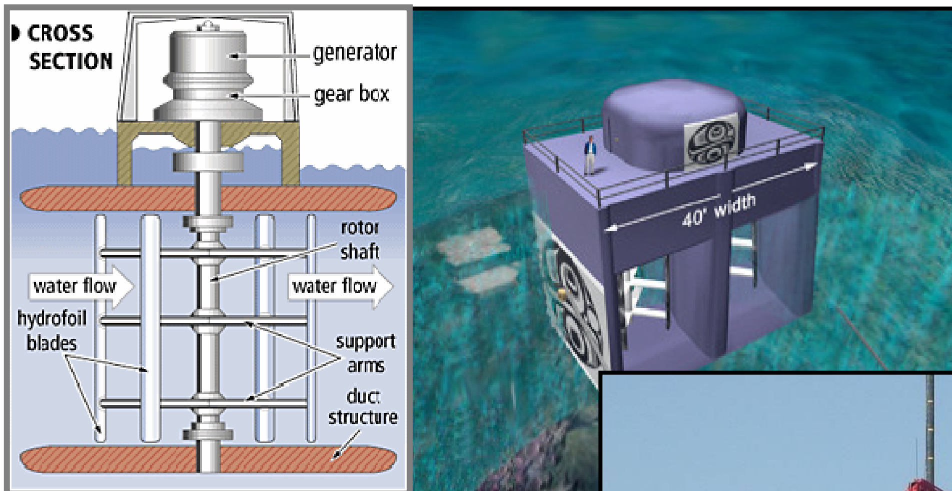


Fig: Vertical axis (Blue Energy)

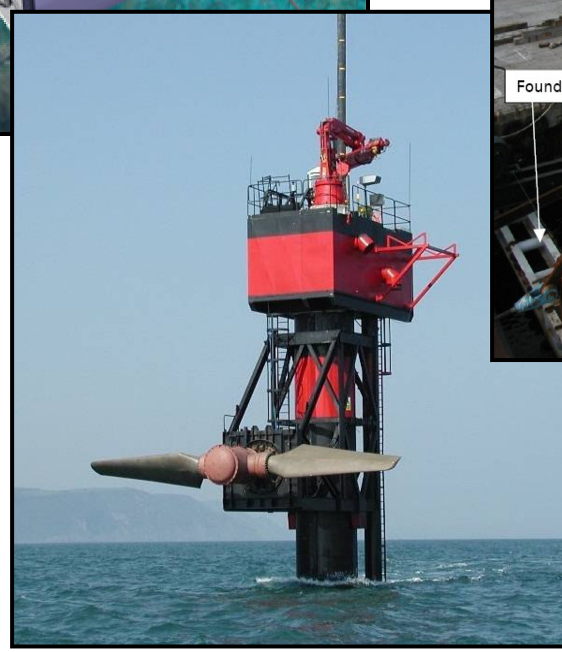


Fig: Horizontal axis (MCT Ltd.)

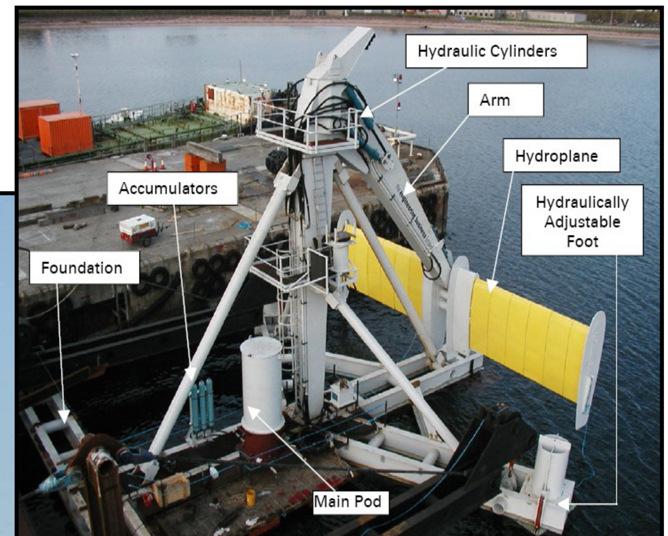


Fig: Reciprocating Hydrofoil (Engineering Business Ltd.)

** High cut-in speed
** Turbine Rotation

Vertical Axis Turbines

Vertical-axis turbines are a type of turbine where the main rotor shaft runs vertically.

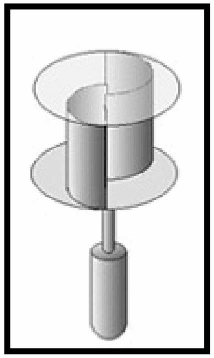
Types:

1. **Savonius Type (Drag Type)**
2. **Darrieus Type (Lift Type)**

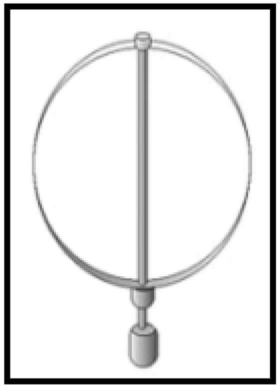
   I. **Egg Beater Type**
   II. **H-Type**

Gorlov, Squirrel cage etc.

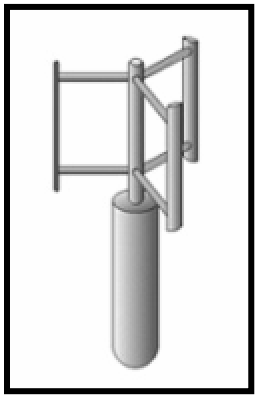
[Turbine rotation is irrespective to the direction of fluid flow]



(1) Savonius type



i. Egg Beater Type



i. H-Type

(2) Darrieus type

Comparison

Savonius Type:

Adv.: High Starting Torque

Dis.: Low Tip Speed Ratio (TSR ≈<1), Low Efficiency

Darrieus Type:

Adv.: High TSR (>1), High Efficiency

Dis.: Low start-up characteristics

TSR (λ) = (Blade Tip Speed/ Water Speed)= ($\omega R/V$)

Advantages of a Hybrid Turbine Design

- Flexibility to meet specific design criteria
- Knowledge of conventional rotors
- Simple in structure
- Easy to build

Prototype Design

Possible Combinations

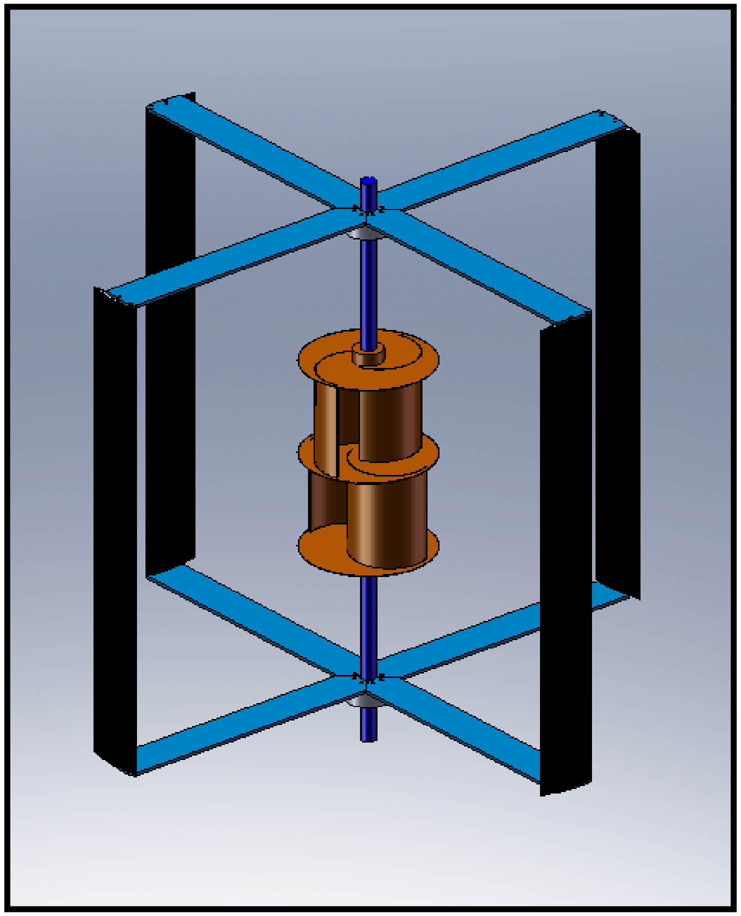


Fig: Type A

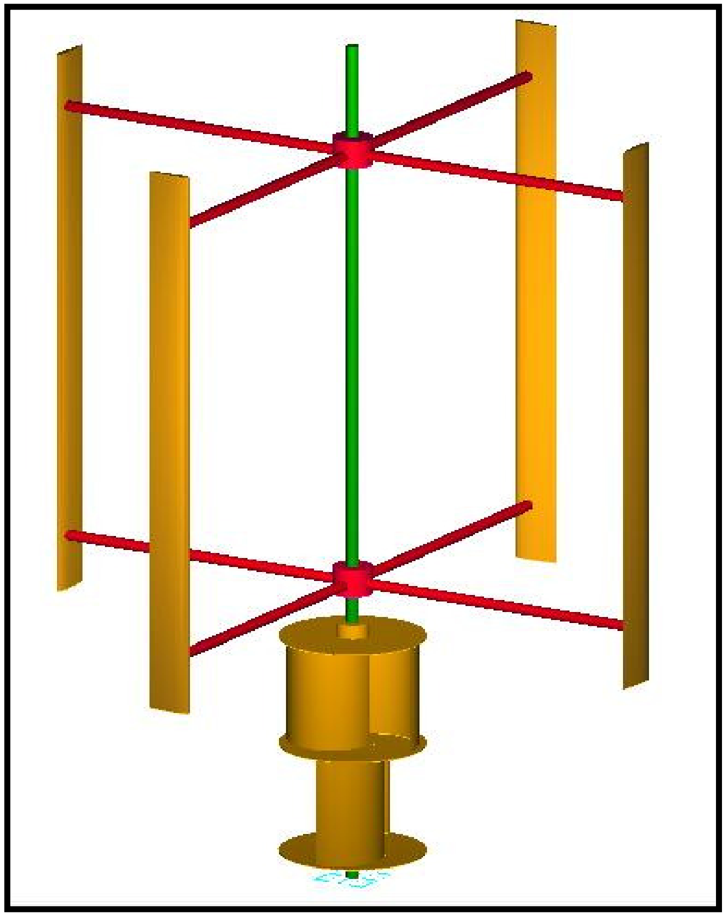


Fig: Type B

Selected Prototype

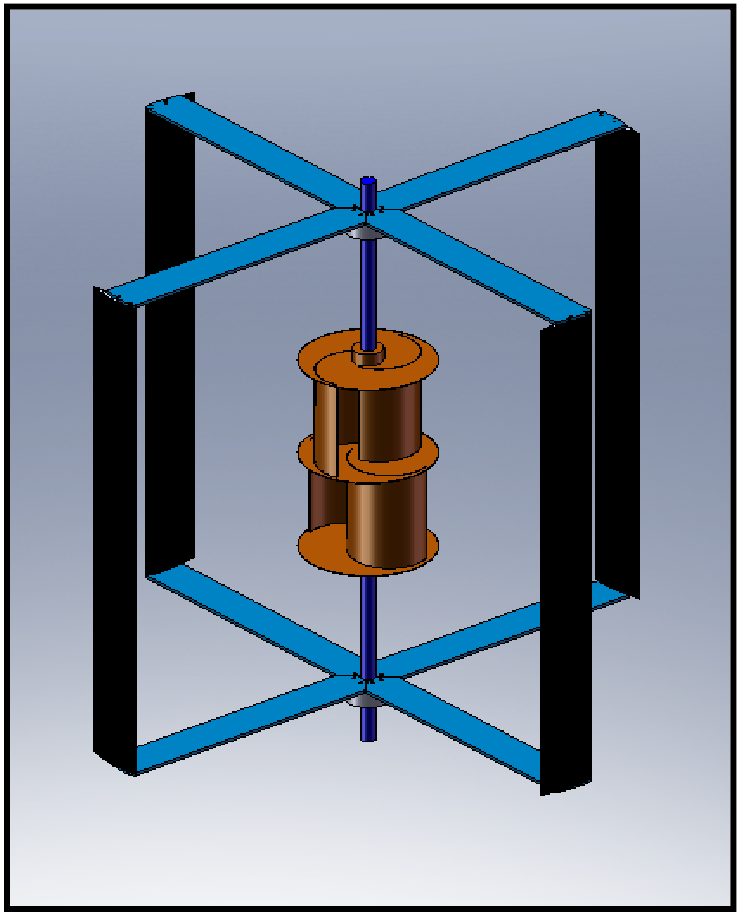


Fig: Hybrid Model (CAD View)

Fig: Hybrid Model (Final product)

Solidity Ratio: ((No. of Blades * Chord Length)/Rotor dia.)

Design Equations & Parameters

Mechanical Power Output of Hybrid Turbine,

$$P = 0.5 \times \rho \times V^3 \times \left(A_s C_{Ps} + (A_d - A_s) C_{Pd}\right) \quad ---- \text{(I)}$$

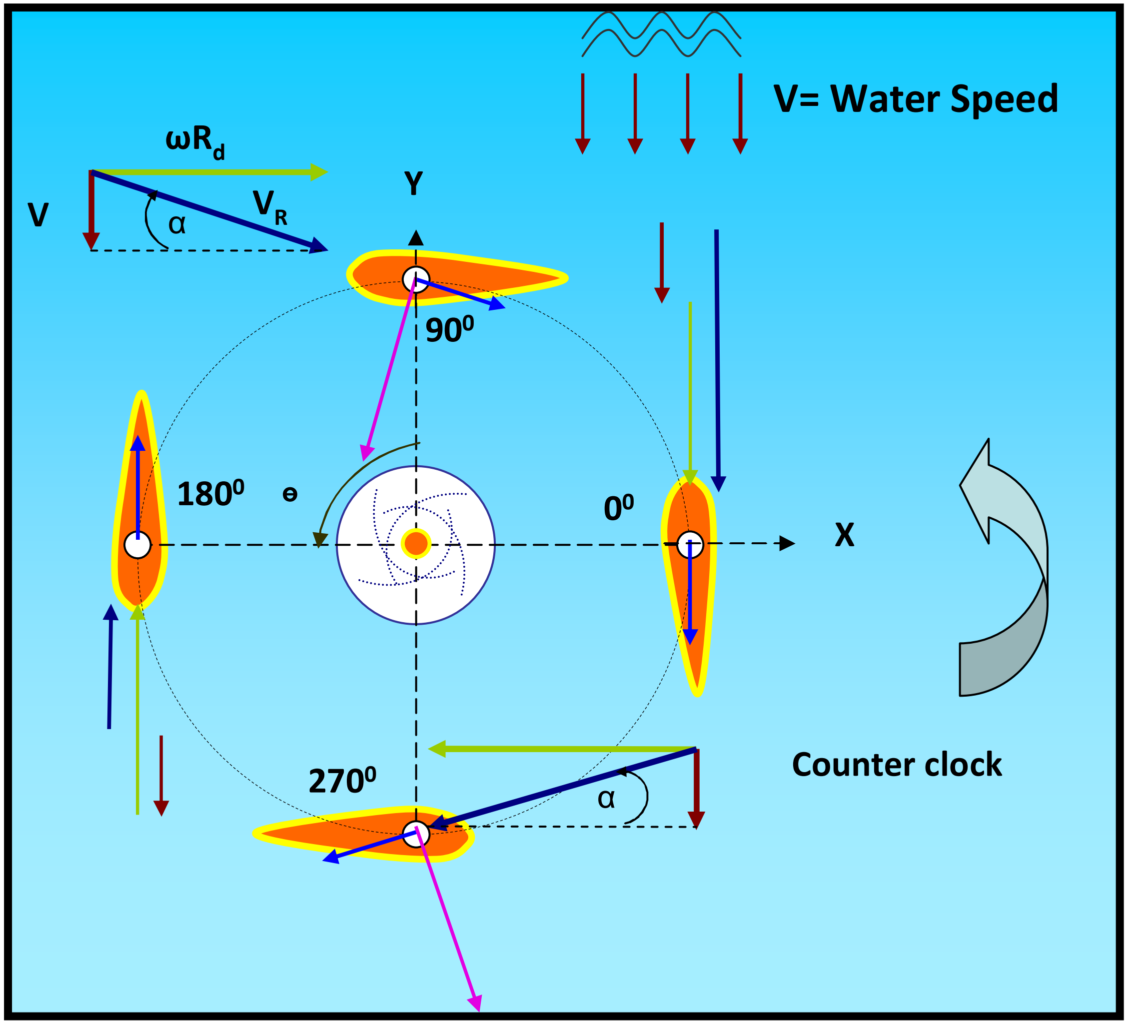
Tip Speed Ratio (TSR),

$$\lambda = \frac{\omega R_d}{V} \quad ---- \text{(II)}$$

Savonius Rotor	
Rotor Height (H_s)	400mm
Nominal diameter of the paddles (d_i)	130mm
Diameter of the shaft (a)	20mm
Rotor diameter (D_s)	200mm
Overlap ratio (β)	0.298
Swept area (A_s)	$0.08m^2$
Darrieus Rotor	
Airfoil Section	NACA 0015
Number of Blades	4
Solidity Ratio [3]	0.40
Rotor diameter (D_d)	1m
Rotor Height (H_d)	1m
Swept area (A_d)	$1m^2$
Chord length (C)	100mm

Solidity Ratio: ((No. of Blades * Chord Length)/Rotor dia.)

Working Principle (Hydrodynamics)



$$V_R = V\sqrt{1 + 2\lambda\cos\theta + \lambda^2}$$

$$\alpha = \tan^{-1}\left(\frac{\sin\theta}{\cos\theta + \lambda}\right)$$

Flume Tank

Fig: Flume Tank (MI)

Fig: Turbine With Frame

Test Setup

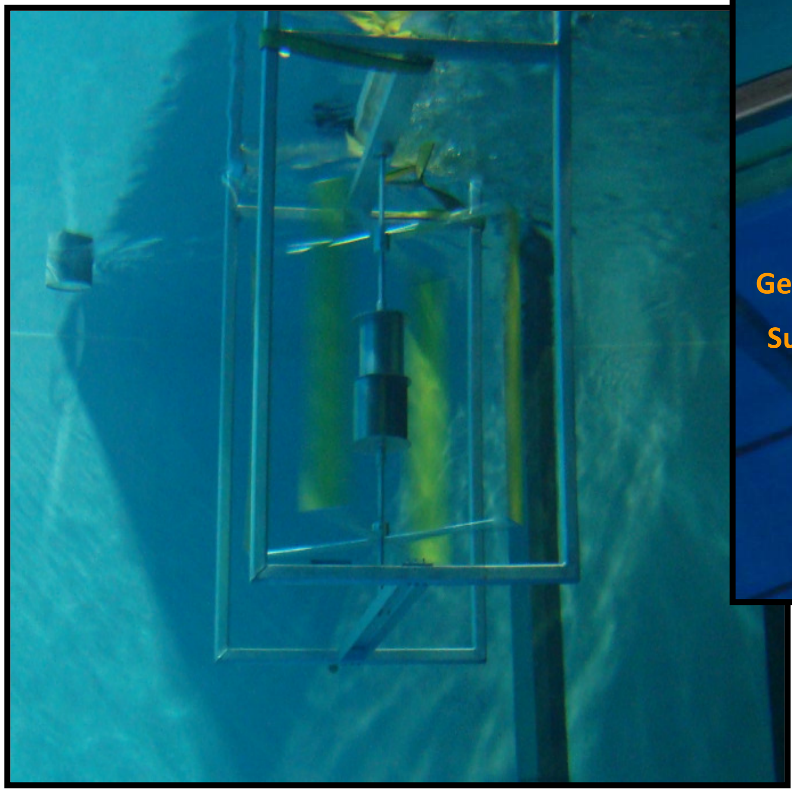


Fig: Submerged Turbine

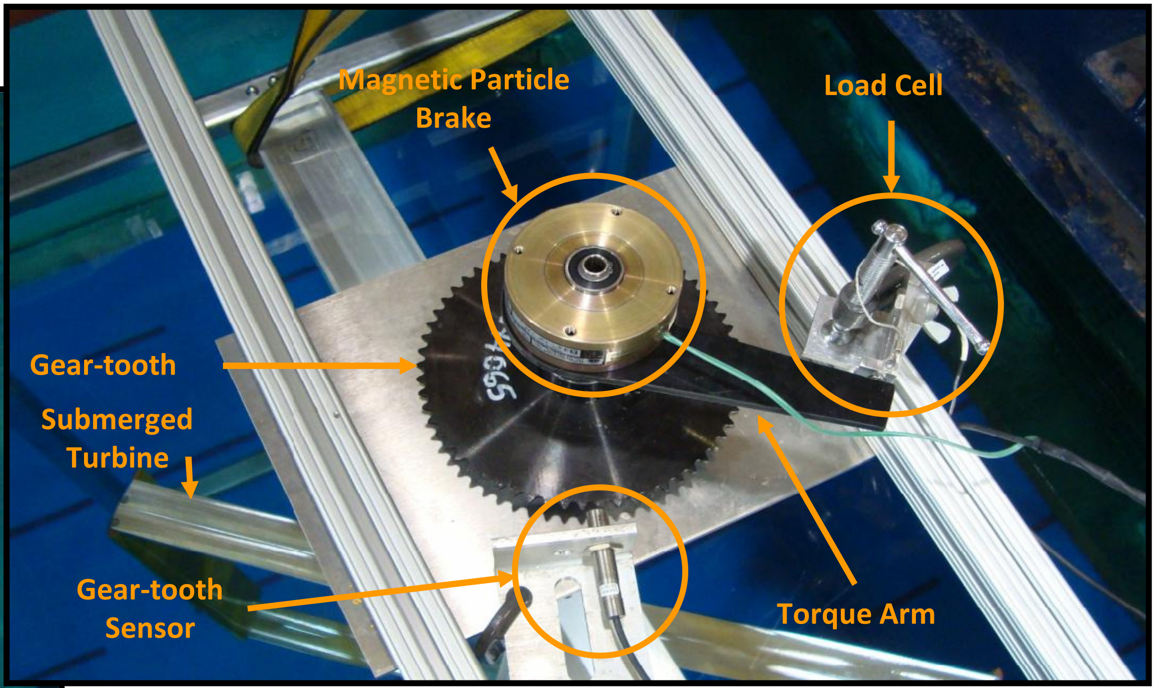


Fig: Torque and Speed Measurement

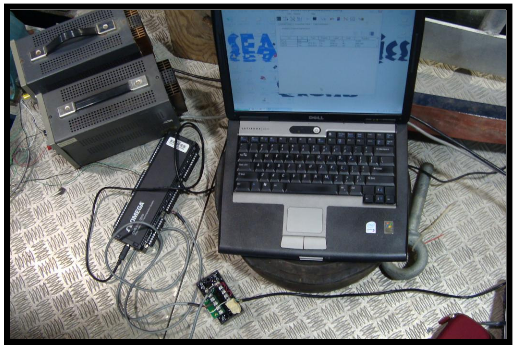


Fig: DAQ board and Data Collection Terminal

Test results

Savonius Test Results

Fig: Two-Stage Savonius

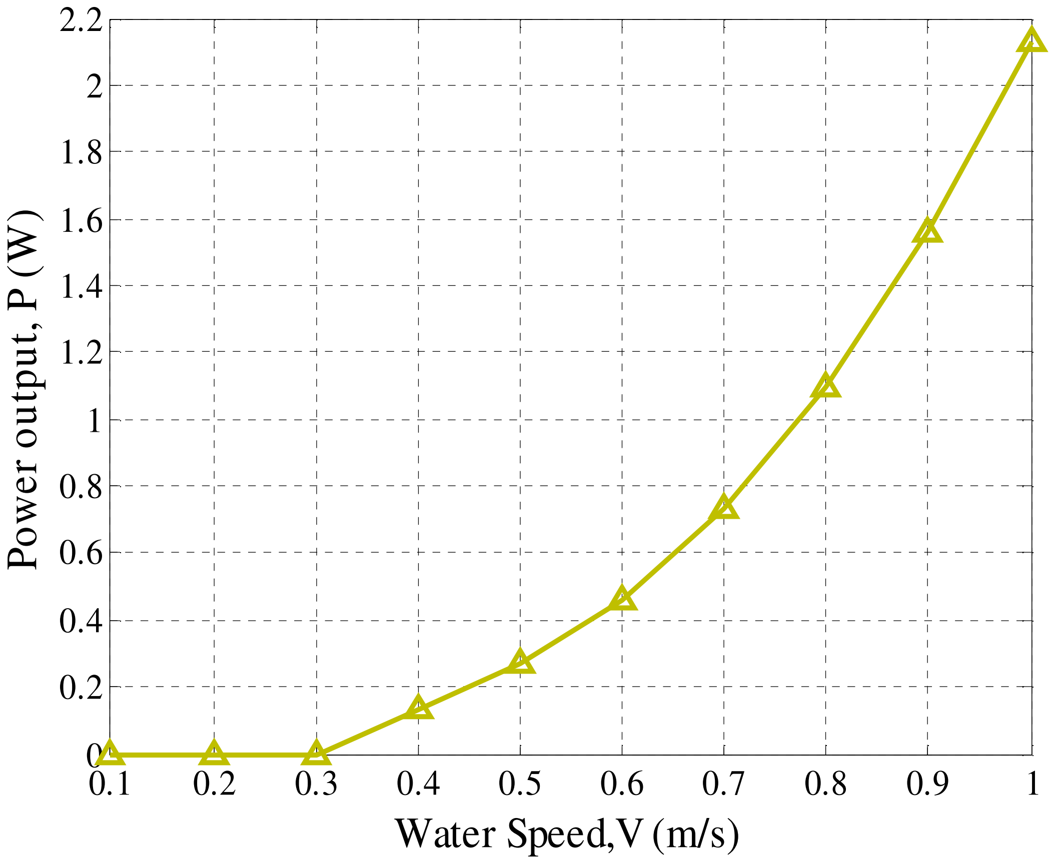
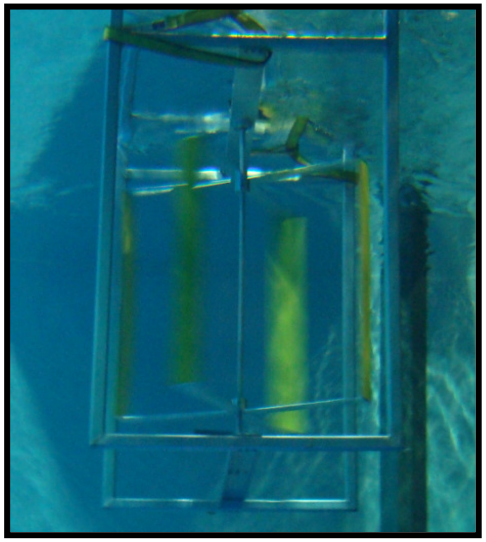


Fig: Power (P) vs. Water Speed (V)

H-Darrieus Test Results



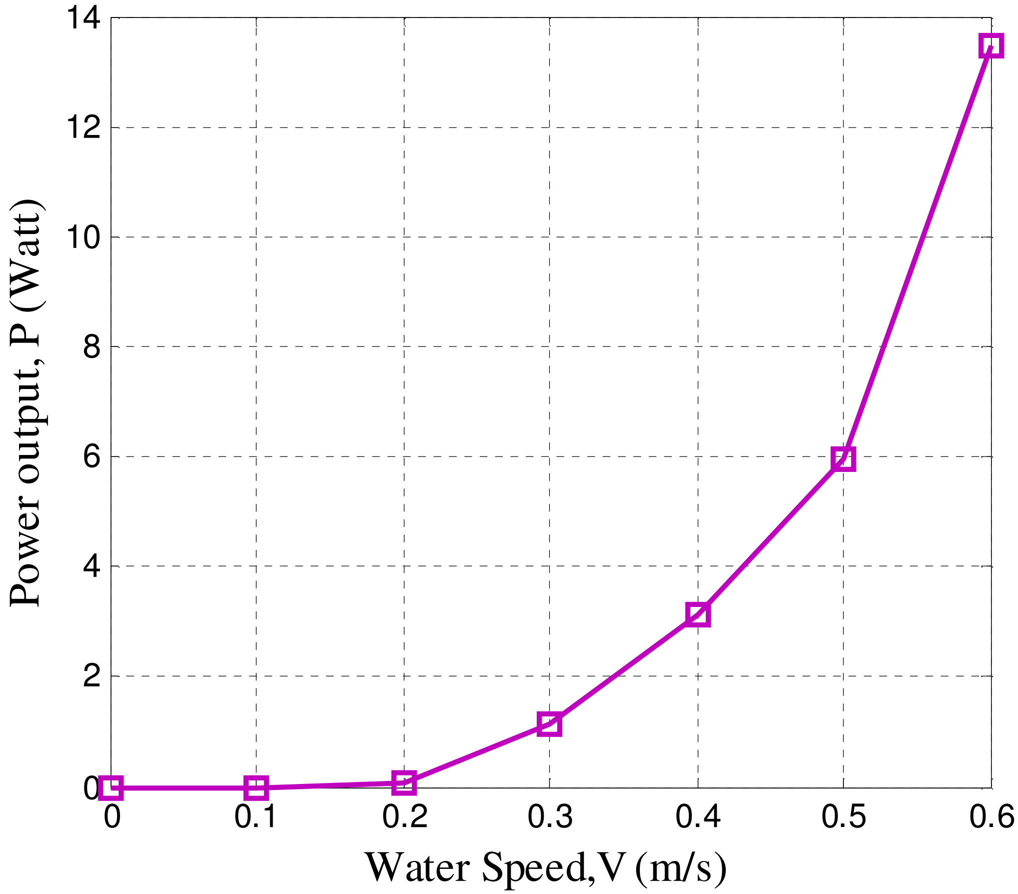


Fig: Power (P) vs. Water Speed (V)

H-Darrieus Test Results

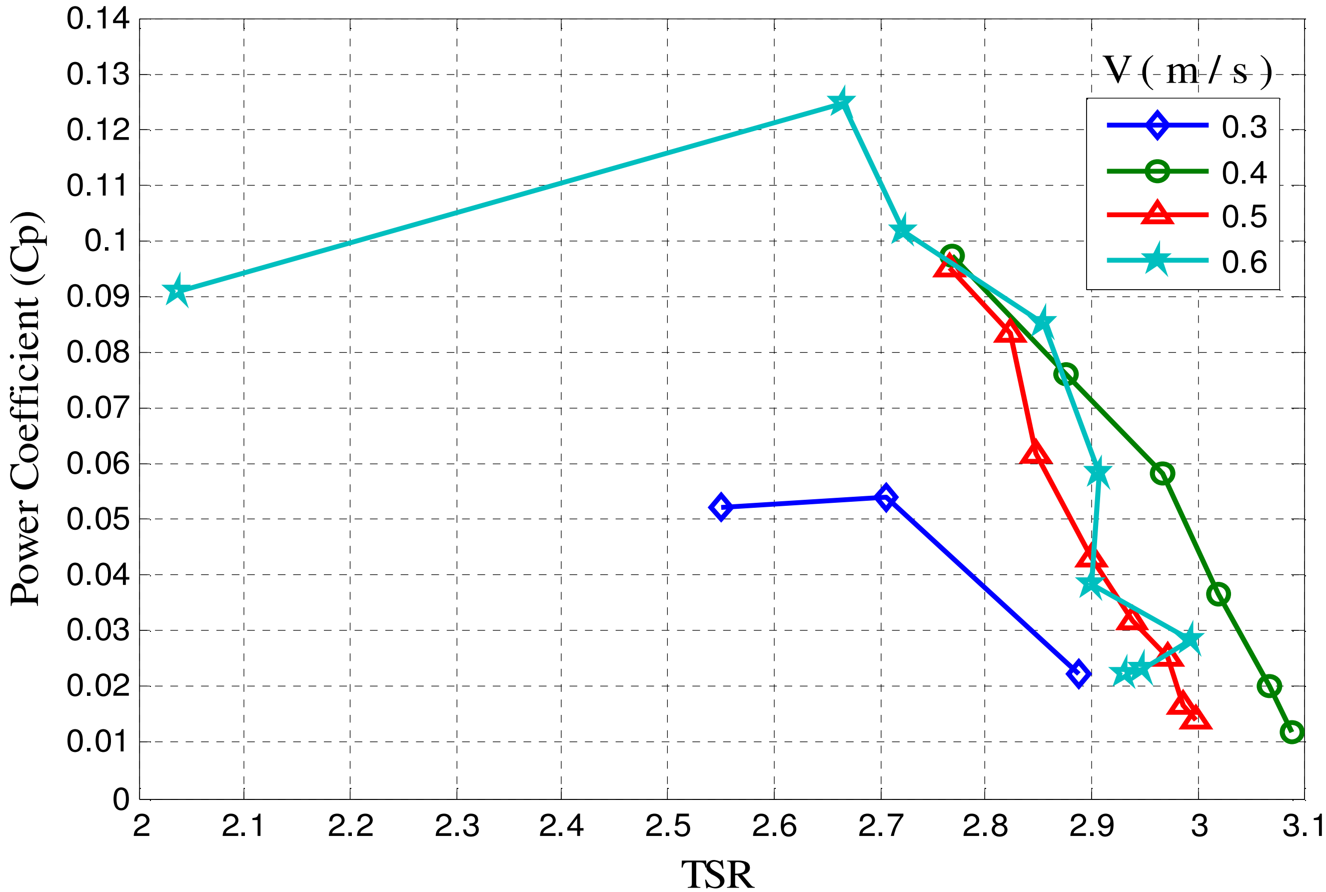


Fig: Power Coefficient vs. TSR (λ) for H-Darrieus

Maximum Cp = 0.1248 @ 0.6m/s, when, TSR = 2.67
Maximum TSR = 3.09 @0.4m/s, when Cp = 0.012

Hybrid Test Results (P vs. V)

Test Results

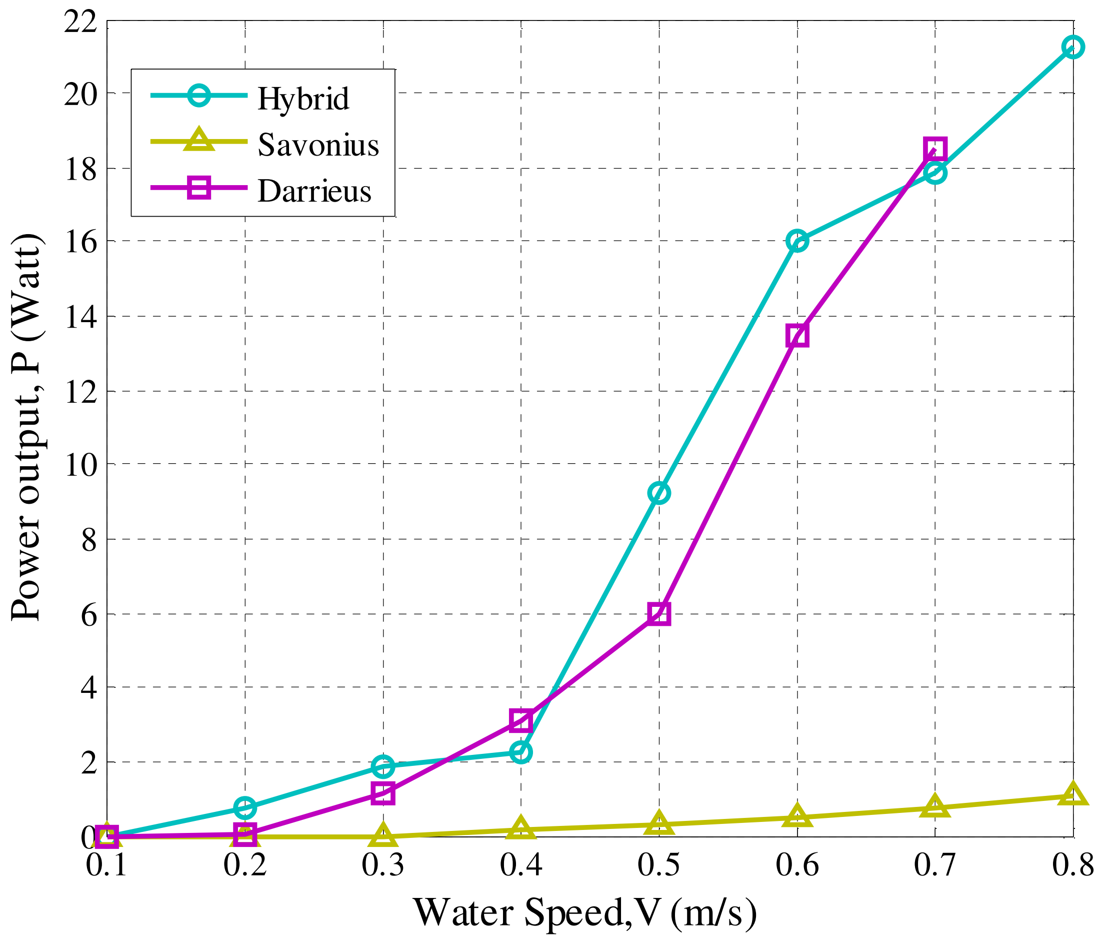
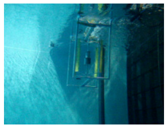


Fig: Power (P) vs. Water Speed (V) for Hybrid Turbine



VIDEO

Hybrid Test Results (P vs. ω)

Test Results

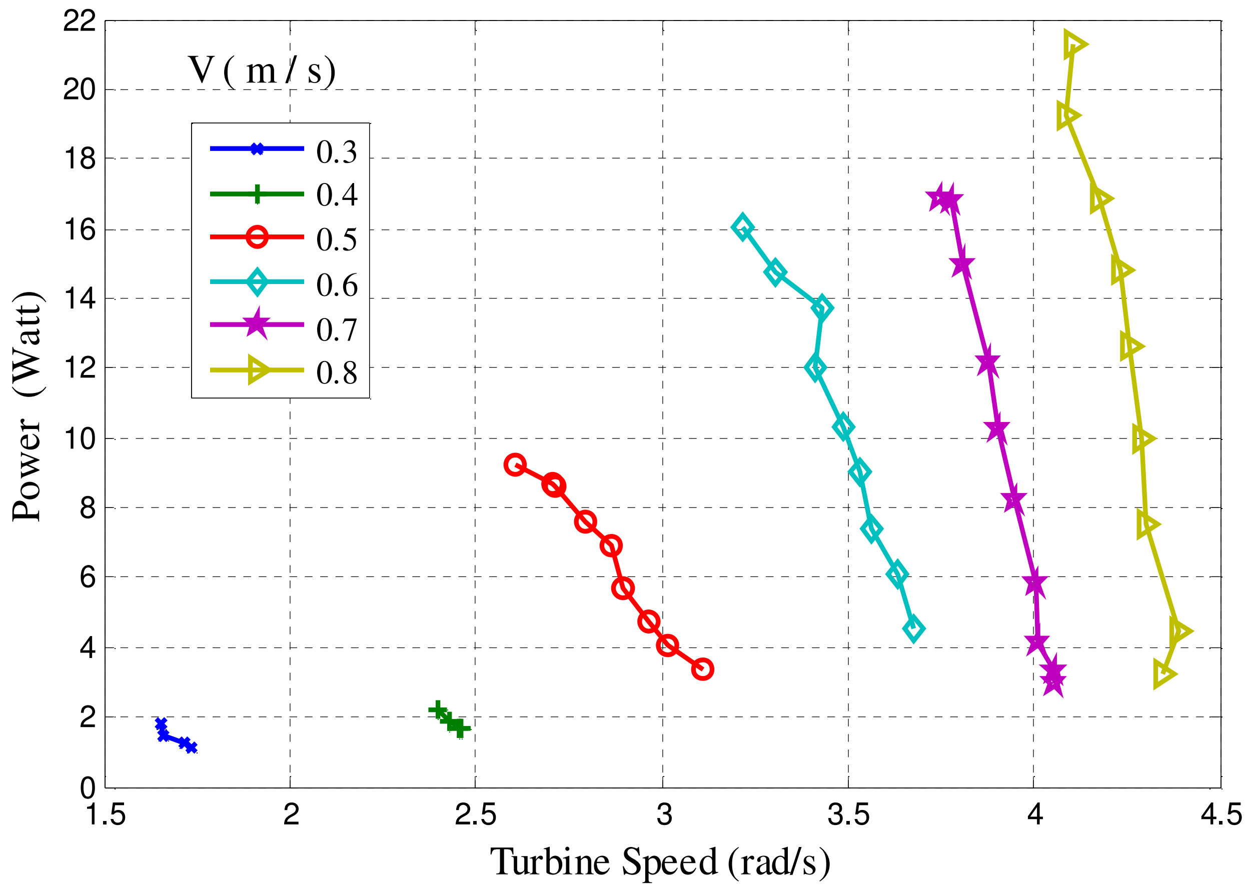


Fig: Power vs. Turbine Speed (ω) for Hybrid Turbine

Hybrid Test Results (C_p vs. λ)

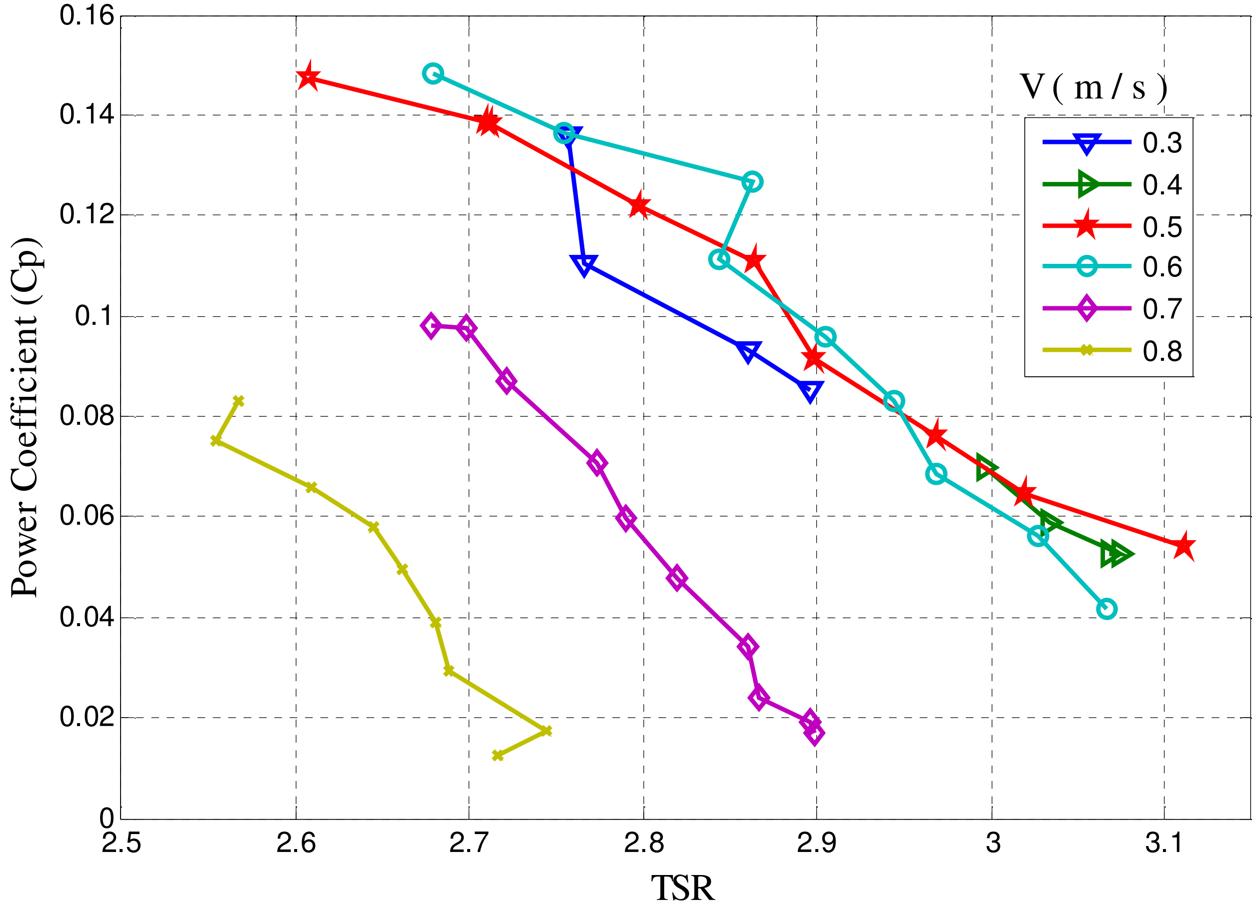


Fig: Power Coefficient vs. TSR (λ) for Hybrid Turbine

Maximum Cp = 0.1484 @ 0.6m/s, when, TSR = 2.6794
Maximum TSR = 3.1114 @0.5m/s, when Cp = 0.0539

Experimental Energy Conversion System

Experimental Energy Conversion System

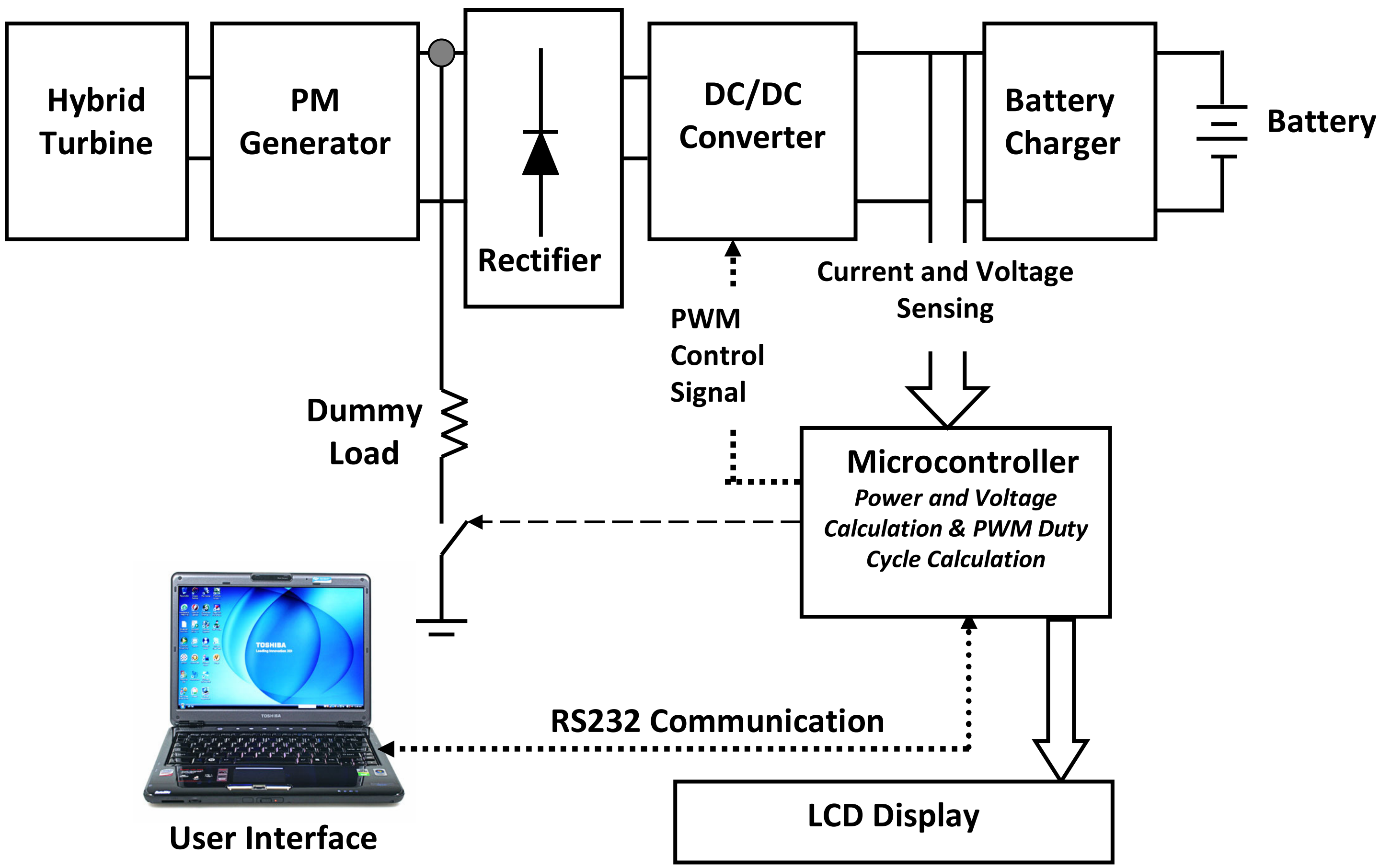


Fig: Experimental Energy Conversion System (MPPT based)

Maximum Power Point Tracker (MPPT)

Experimental Conversion System

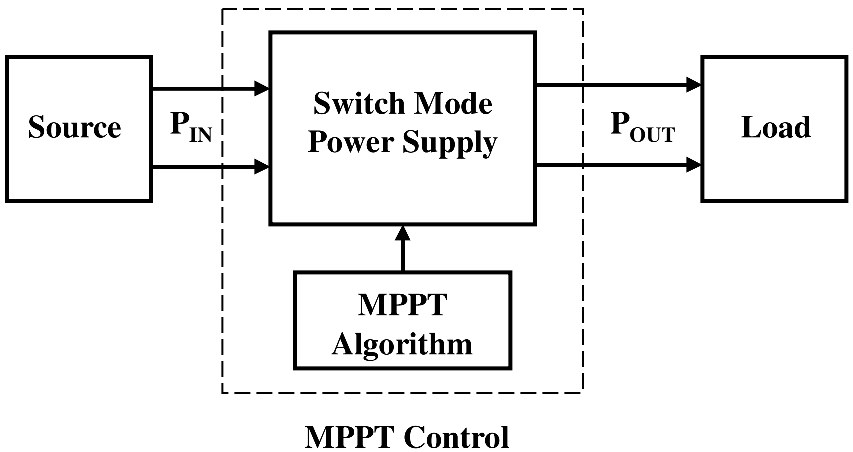


Fig. Basic MPPT control blocks

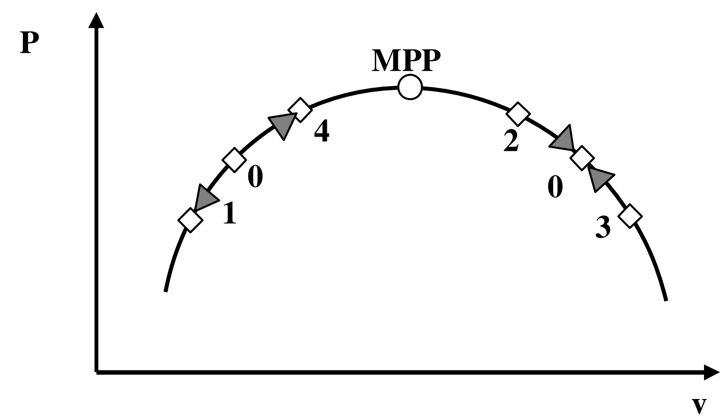


Fig. MPPT Actions (Graphical View of P & O)

Case	dP	dv	Action
0⟶1	<0	<0	+
2⟶0	<0	>0	-
3⟶0	>0	<0	-
0⟶4	>0	>0	+

Fig. MPPT Actions

MPPT Algorithm (Perturbation & Observation)

Experimental Conversion System

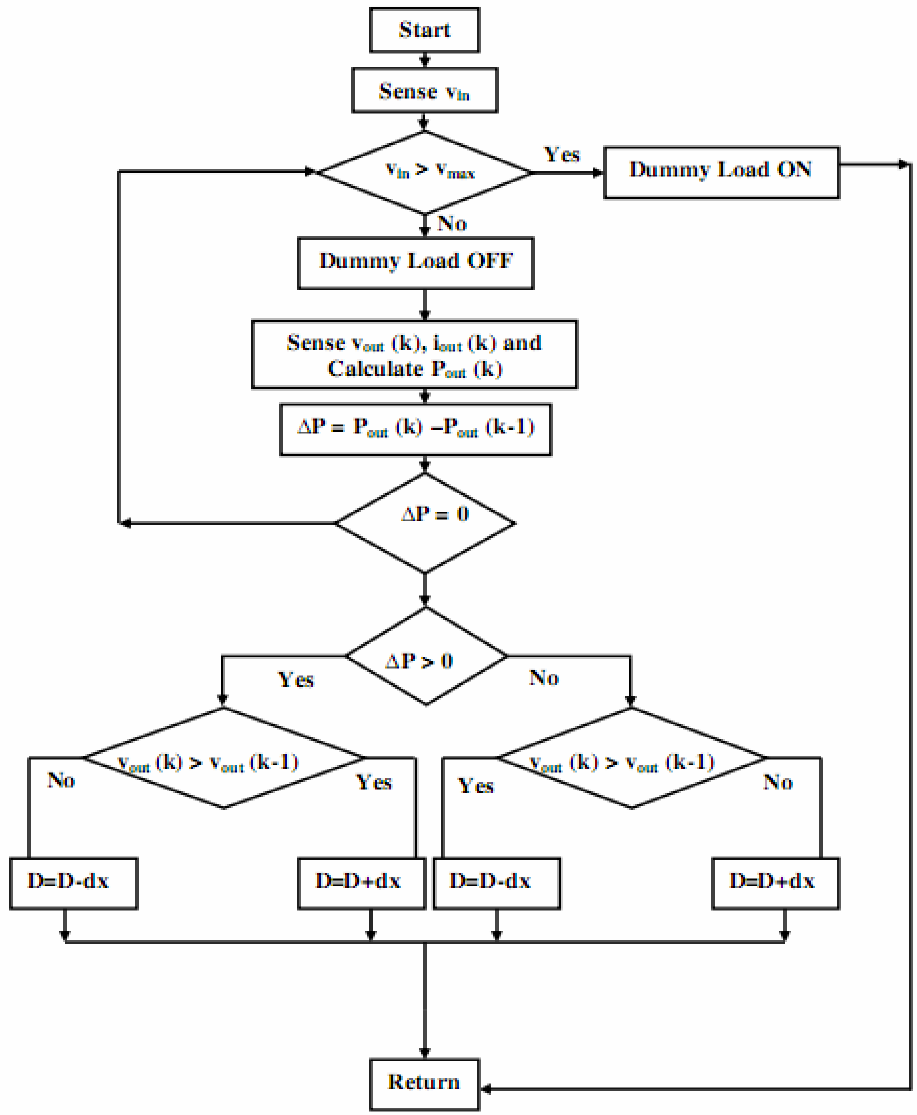
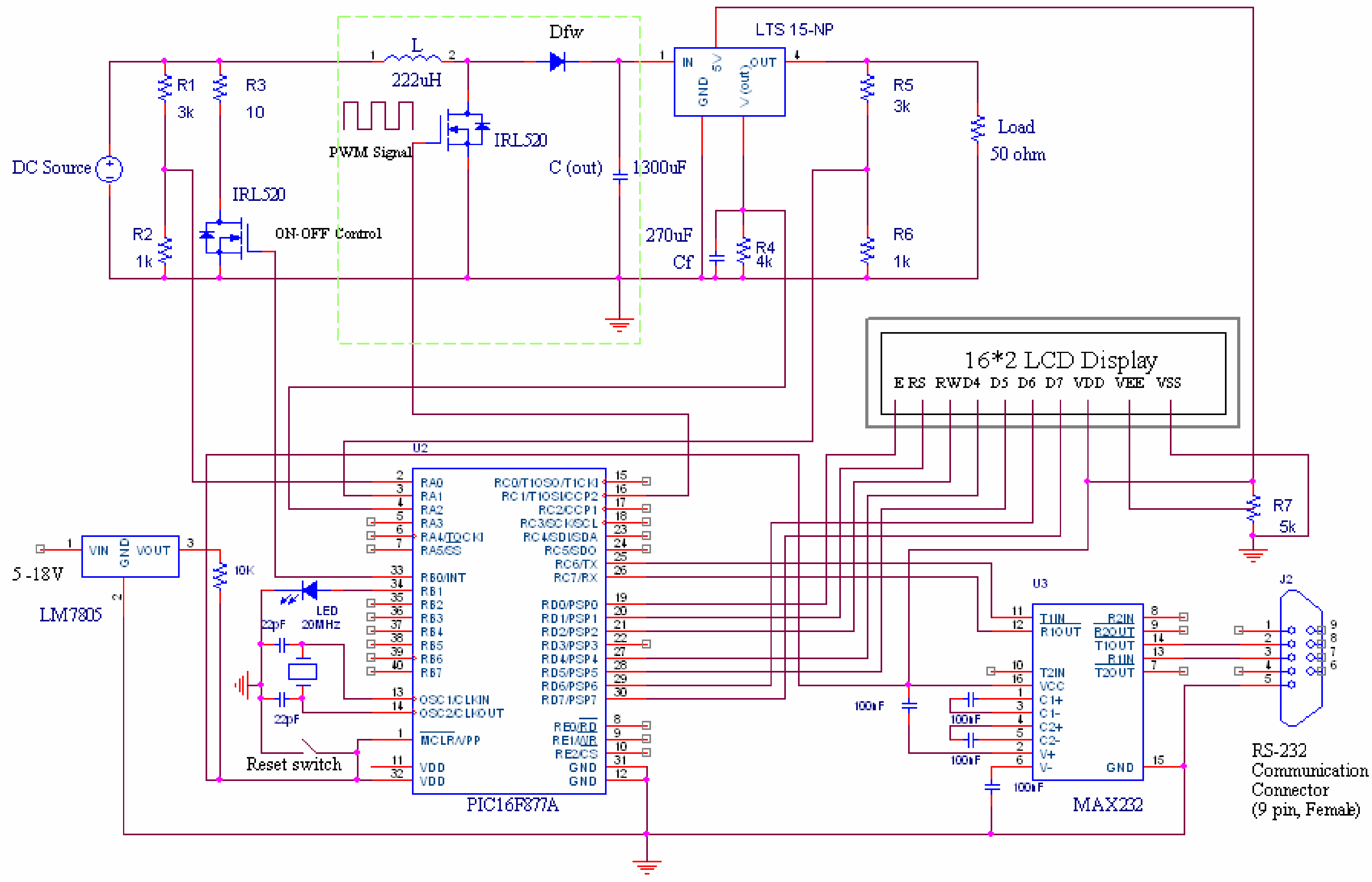


Fig: MPPT Flow Chart

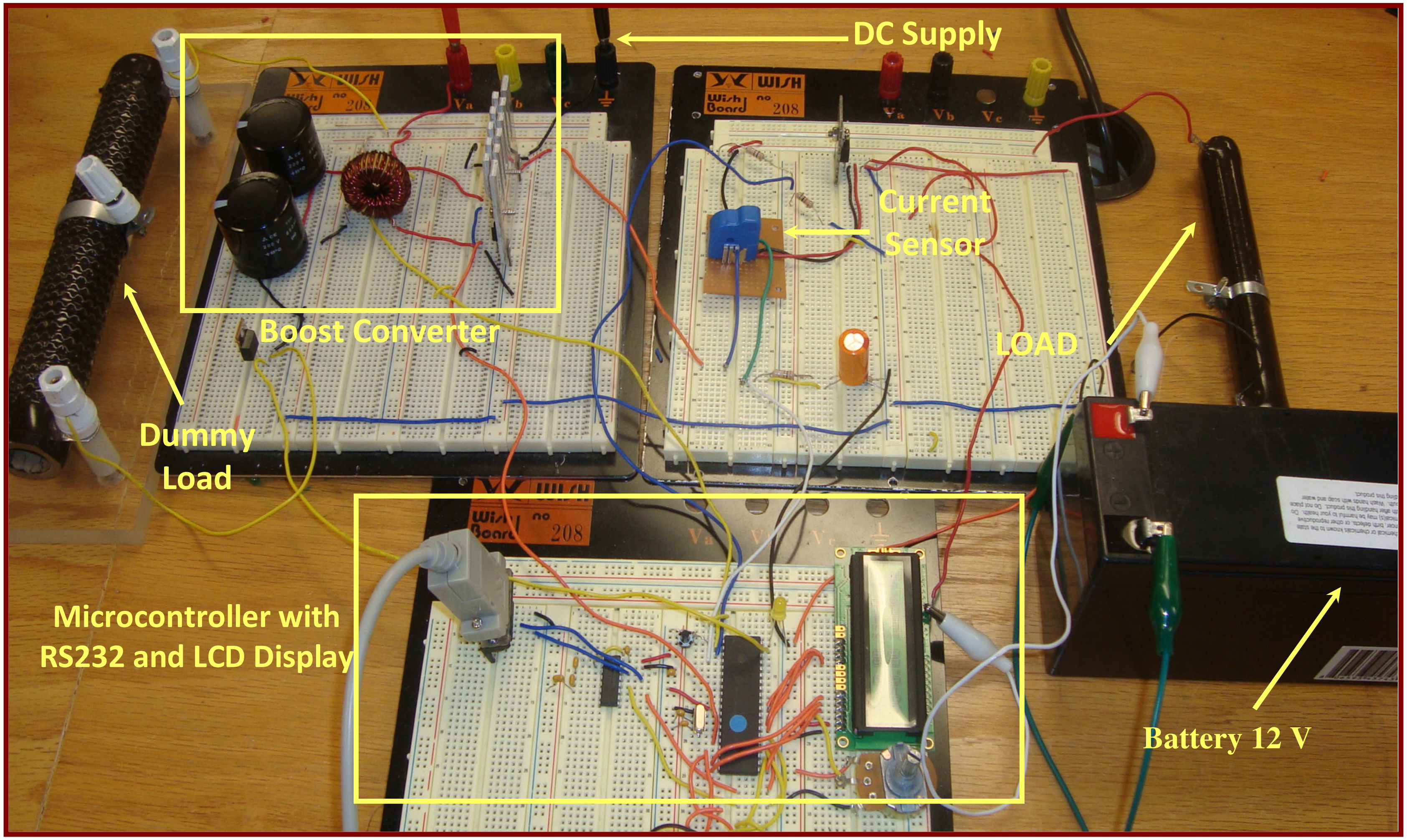
Detailed Circuit Diagram



Main features

- Low cost microcontroller based
- Less complexity
- Easily extendable
- Minimize the size due to less components

Laboratory Setup



Test Result (Boost Converter)

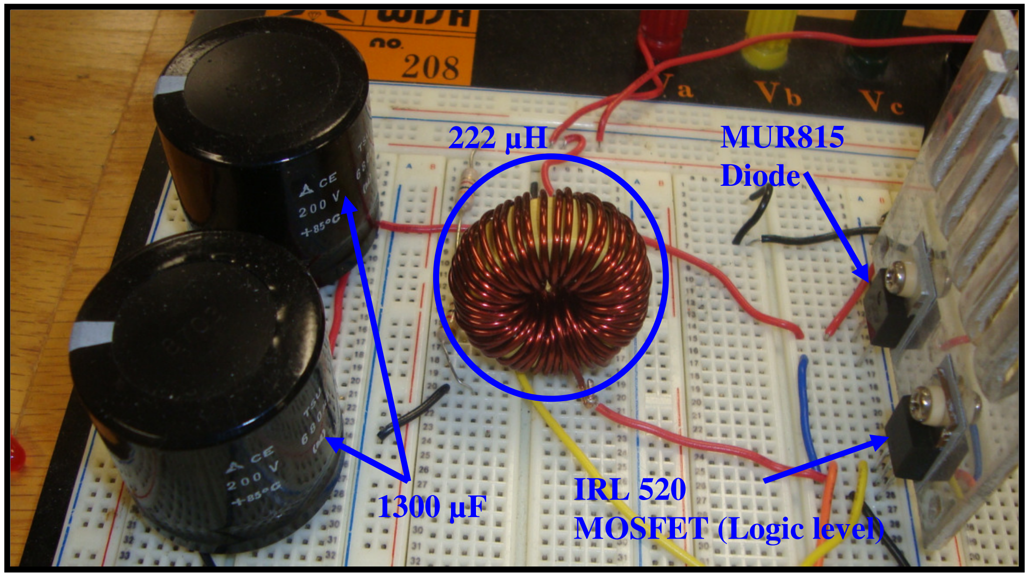


Fig: Boost Converter

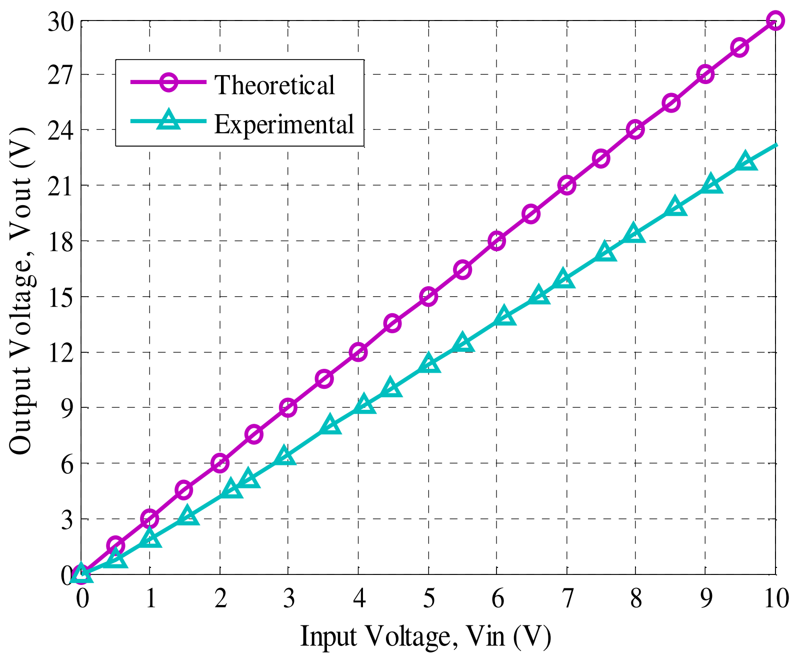


Fig: V_{out} vs. V_{in}

Test Result (MPPT)

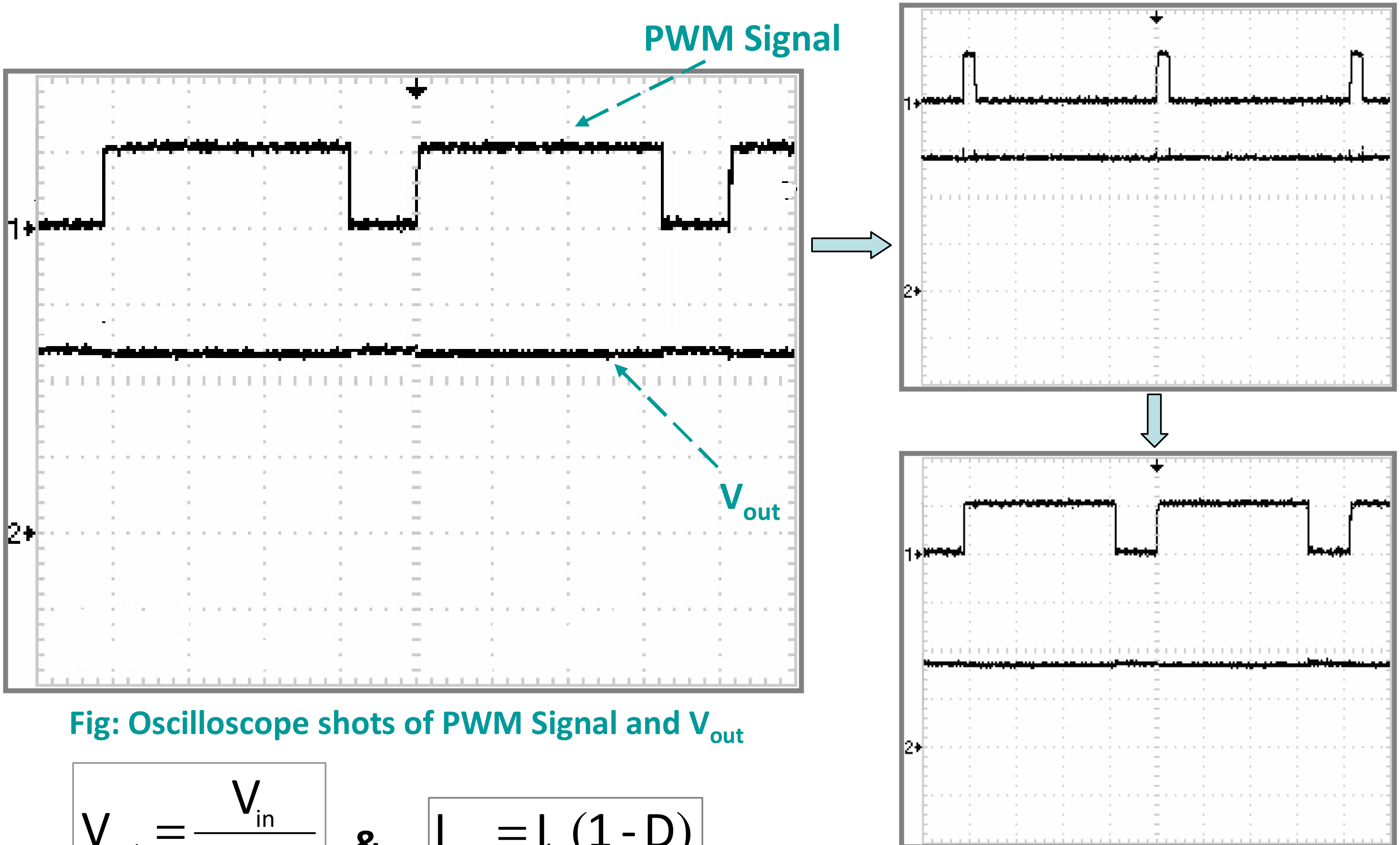


Fig: Oscilloscope shots of PWM Signal and V_{out}

$$V_{out} = \frac{V_{in}}{(1 - D)}$$ & $$I_{out} = I_{in}(1 - D)$$

** 5 Volt/Div

Conclusions

Thesis Contribution

- A simple, low cut-in speed, high TSR, lift type hybrid turbine has been designed.
- Designed turbine has been built, tested and analyzed in a real world situation.
- A low cost microcontroller based experimental energy conversion system has been built and tested.
- A MPPT control algorithm has been tested for the design conversion system.

Future Work and Suggestions

- More water speed data should be collected at other areas of St.John's.
- A CFD (Computational Fluid Dynamics) analysis should be done before the actual design and test.
- To get a higher torque at a comparatively low TSR, cambered airfoil (for example, NACA 4415) can be used.
- A low speed DC PMG can be used to avoid gearbox and rectifier losses.
- More sophisticated MPPT algorithm and digital filtering can be introduced in the control system.

Acknowledgements

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Publications

- "*Design and Development of Hybrid Vertical Axis Turbine*" presented at 22nd CCECE'09, St.John's, NL, Canada, 03-06 May, 2009, pp.1178-1183.

- "*A Low Cut-in Speed Marine Current Turbine*" submitted to Journal of Ocean Technology, 2009.

Thanks