PERMANENT MAGNET SYNCHRONOUS GENERATOR BASED WIND ENERGY CONVERSION SYSTEM

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Abstract - *For India's renewable energy sector to grow sustainably, wind energy will be essential. The tip speed ratio needs to be kept at its ideal level in order for a wind turbine to obtain the most power possible from its speed in range-cut in to rated. Maximum power point tracking refers to the entire procedure of reaching the maximum power, and this is known as the tip speed ratio control (MPPT). The two MPPT methods—(i) the perturb and observe technique (P&O) and (ii) the particle swarm optimisation algorithm method (PSO)—are presented in this research. The algorithm block receives the voltage and current from the dc side as input, and it outputs the duty ratio, which is sent to the dc-dc boost converter. Both constant and variable speed wind input the model's simulation and analysis are carried out using MATLAB (simulink). Using a permanent magnet synchronous generator (PMSG), a model of a variable-speed wind turbine is shown, along with suggested control strategies. The model displays the mechanical, electrical, and aerodynamic components of the wind turbine. Matlab/Simulink simulations have been run to validate the model and suggested control strategies.*

***Keywords*: Wind Turbine, Permanent Magnet Synchronous Generator, Maximum Power Point Tracking (MPPT), Perturb & Observe (P&O), Particle Swarm Optimization (PSO). Boost converter**

1. Introduction

The urgent need to replace fossil fuels due to their detrimental environmental effects, such as pollution and the greenhouse effect, has increased in recent years, making renewable energy sources (RESs) an essential part of the answer. Because of its benefits to the environment and the economy, wind energy is one of the main RESs [1]. According to predictions, 20% of the world's energy will come from wind power by 2030 [2].

Two distinct wind turbines (WT) are used in the wind energy conversion system (WECS) configuration and are available on the international market. Compared to a variable speed wind turbine, the fixed speed wind turbine (FSWT) is straightforward to install and manage (VSWT). The VSWT, however, offers the benefits of improved energy collection, lower load transient load reduction, and total load reduction controllability [3]. In variable-speed WECSs, a variety of generator types are used, including permanent magnet synchro- nous generators (PMSGs), doubly fed induction generators, and squirrel cage induction generators (SCIGs) [4, 5, 6]. Researchers have expanded utilisation of PMSGs in variable speed WECSs due to high power density, high performance efficiency, and high reliability even though DFIGs with partial power converters is a strong commercial contender. Additionally, the wide operating speed range and lack of DC excitation increase the WECSs efficiency by 10% [8–10]. Researchers are now looking at multi-phase machines to lessen torque pulsations and current per phase fluctuations while also enhancing fault tolerant capabilities (FTC) [11,12].

Although they are used in WECSs, the dual-three-phase machines [13] and the siX-phase machines [14] need for sophisticated control systems and pricey converters. Five-phase PMSGs are being used in numerous applications, including small-scale WECSs and maritime turbines [15, 16]. To optimise the power generated by the wind and to complete essential tasks of utility grid integration, the five-phase PMSG is used in conjunction with an effective control system for wind power generating [17]. The 1.5 MW five-phase PMSG used in the variable-speed WECS arrangement is integrated with the utility grid (UG) via a frequency converter. The machine side converter (MSC) and the grid side converter are two categories for the frequency converter (GSC). In order to extract the best produced power at each different wind speed and inject the active power into the UG with unity power factor (UPF), the frequency converter applies the back-to-back converter (BTBC) through the DC-link capacitor [18].

To increase the amount of wind-generated electricity, a number of maximum power point tracking (MPPT) algorithms have been suggested [3,6]. They are often divided into two groups: indirect power controllers (IPC) and direct power controllers (DPC). Several other MPPT algorithms, including the tip speed ratio (TSR), the optimal torque (OT) [19], and the power signal feed-back (PSF) [20], are implemented by the IPC control. The TSR

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algorithm is a simple and effective way to control the generator speed under a variety of weather circumstances.

From above discussion this research prefers standalone mode for PMSG based wind energy conversion system. This paper deals with P&O and PSO techniques for maximum power point tracking. The remaining sections are followings: Section II deals with wind energy conversion system, Sections III equipped with MPPT techniques, Section IV elaborates the simulation results and Section V describes the conclusion of research work.

II. Wind Energy Conversion System (WECS)

2.1. Wind Turbine

The equation for mechanical power of WT is expressed using Eq. (1) as,

$$P_m = \frac{1}{2}\rho A C_p(\lambda,\beta) V_w^{\ 3} \qquad (1)$$

where ρ is air density, A is turbine swept area and Vw is wind speed. The power coefficient is represented by Cp which is a nonlinear function of tip speed ratio (λ) and blade pitch angle (β) and is expressed using Eq. (2). The C_p has a theoretical value of 0.59 [21].

$$C_p(\lambda,\beta) = c_1\left(\frac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{-\frac{c_5}{\lambda_i}} + c_6\lambda$$

(2)

Where,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{1+\beta^2} \qquad (3)$$

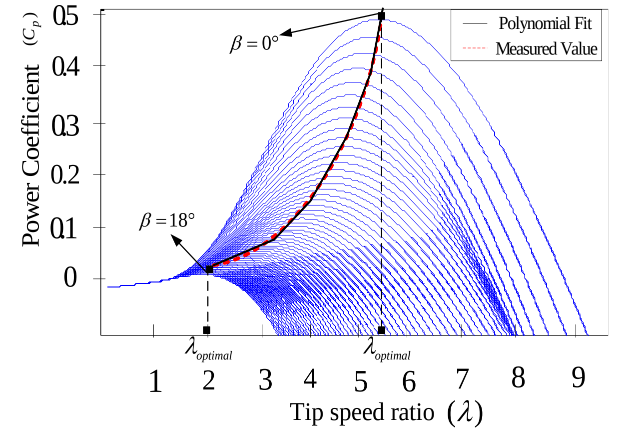
The tip speed ratio λ of the WT is expressed using Eq. (4) as,

$$\lambda = \frac{\Omega_t R}{V_w} \qquad (4)$$

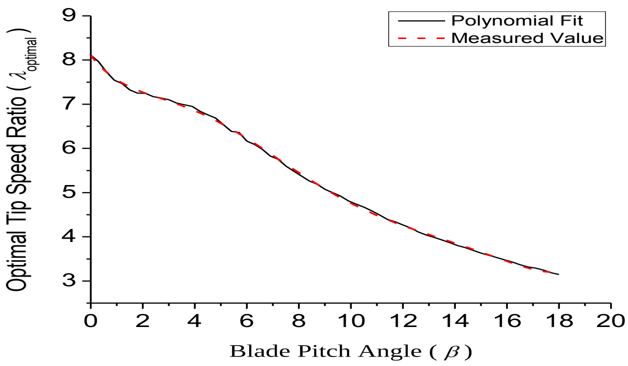
where, Ωt is the rotor speed, R is the radius. The developed mechanical torque τ_m of the WT can be expressed as,

$$\tau_m = \frac{P_m}{\Omega_t} \qquad (5)$$

The relationship between C_p and λ developed using the measured data from the simulation of WT is shown in Fig. 2(a)-(b).



(a) C_p - λ curve



(b) $\lambda_{optimal}$ - β curve

Figure 2(a)-(b). Polynomial fit of measured data.

From Fig. 2(a) it can be observed that the optimal value of the λ varies with β for maximizing the value of Cp. Therefore, a relationship is developed between β and $\lambda_{optimal}$ to track C_p to maximum value and is expressed in Eq. (6) [22].

$$\lambda_{optimal} = \alpha - \gamma_1\beta + \gamma_2\beta^2 - \gamma_3\beta^3 + \gamma_4\beta^4 - \gamma_5\beta^5 + \gamma_6\beta^6 \qquad (6)$$

Eq. (6) is acquired by using polynomial fit method and plotted in Fig. 2(b).

2.2 Permanent Magnet Synchronous Generator (PMSG)

The mathematical model of a PMSG is developed in the direct-quadrature (d-q) reference frame. The modeling of the PMSG in state equation is expressed using Eq. (7) & (8) as,

$$\frac{di_d}{dt}=\frac{1}{L_{ds}+L_{ls}}(-R_s i_d+\omega_e(L_{qs}+L_{ls})i_q+u_d) \quad (7)$$

$$\frac{di_q}{dt}=\frac{1}{L_{qs}+L_{ls}}(-R_s i_q+\omega_e(L_{qs}+L_{ls})i_d+u_q) \quad (8)$$

where, R_s is the stator resistance, i_d and i_q are the currents, L_d and L_q are the inductances of the generator along the d and q axis, L_{ls} is the leakage inductance of the generator and ω_e is the electrical rotating speed (rad/s) of the generator [23].

The electromagnetic torque (Tem) of the PMSG is expressed using the Eq. (9) as,

$$T_{em}=1.5p((L_{ds}-L_{ls})i_d i_q+i_q\psi_f) \quad (9)$$

Where, ψ_f is the permanent magnetic flux.

III. Boost Converter & MPPT Techniques

3.1 Boost Converter

The boost converter's main purpose is to raise the voltage. Fig. 3.1 depicts the boost converter's circuit configuration.

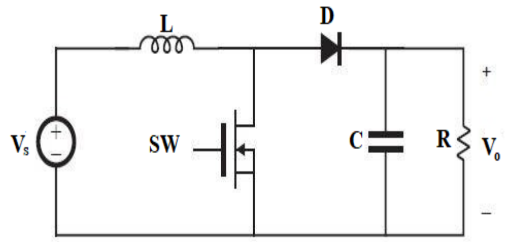


Fig. 3.1 Circuit Diagram of Boost Converter

During the ON period of the switching element, the inductor's current starts to increase and it begins to store energy. It is said that the circuit is charging. The inductor's reserve energy begins draining into the load and the supply while it is in the OFF position [24]. The inductor time constant affects the output voltage level, which is greater than the input voltage level. The switching device's duty ratio and source side voltage are compared to determine the load side voltage.

3.1.1 OPERATING MODES OF BOOST CONVERTERS

The operation of Boost Converter can be classified in two modes:

(a) Mode I Operation of Boost Converters:

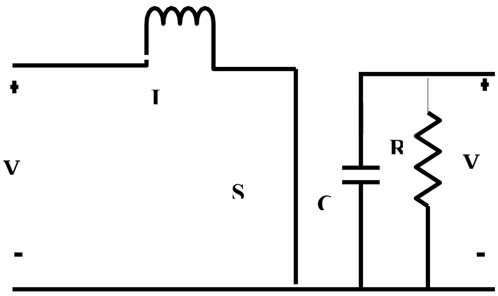


Fig. 3.2 Mode I of Boost Converter

When the switch is closed, the source voltage charges the inductor, which then stores the energy. Although the inductor current grows exponentially in this mode, we'll assume for the sake of simplicity that it charges and discharges in a linear fashion [25]. Since the diode prevents current from flowing, the load current, which is provided by the discharge of the capacitor, remains constant.

(b) Mode II Operation of Boost Converters:

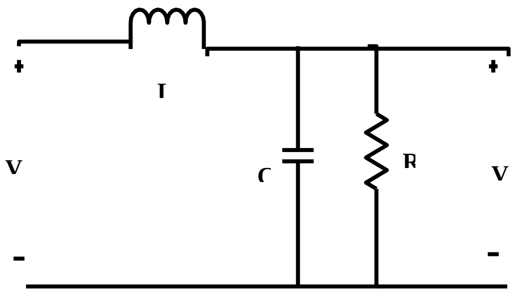


Fig. 3.3 Mode II of Boost Converter

In mode II, the switch opens, short-circuiting the diode as a result. Through opposing polarities, the inductor's stored energy is released, which charges the capacitor [26]. The output voltage is the result of adding V_S and V_L while the load current stays constant.

3.2 MPPT Techniques

The two MPPT methods used in this project are-(i)Perturb and Observe Method

(ii) Particle Swarm Optimization

Let us discuss them in detail.

(i) PERTURB AND OBSERVE (P&O) ALGORITHM BASED MPPT:

It monitors the power fluctuation and, in response, makes modifications to the relevant parameter, such as the duty cycle of the DC-DC converter to control the dc voltage or to regulate current to change the rotor speed and track the MPP. This approach is based on randomly perturbing control variables in tiny stages, then choosing the next perturbation depending on how the power curve has changed as a result of the previous perturbation. Due to its simplicity and lack of a mechanical speed sensor or anemometer, the P&O technique is a commonly used MPPT algorithm [27].

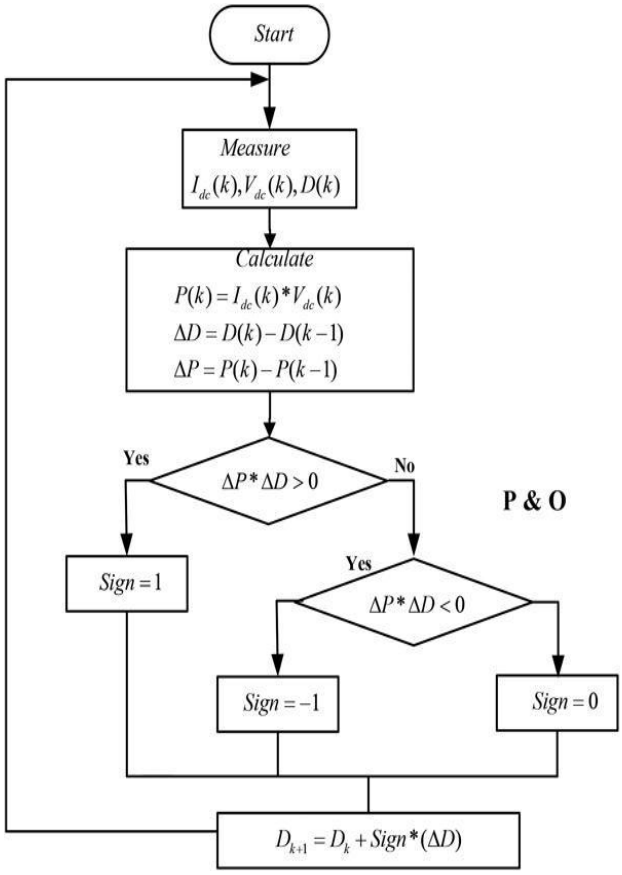


Fig. 3.4 P&O Flowchart

Where, D=duty cycle;

I=Current;

V=Voltage;

P=Power;

Subscript k denotes the value at a particular instant;

Subscript k-1 denotes the value at previous instant;

Subscript k+1 denotes the value at succeeding instant

(ii) PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM BASED MPPT:

Due to its shown resilience, simplicity of usage, and potential for global exploration across a range of applications, PSO is an evolutionary computing approach that is often used. It searches the optimised particle's position and velocity in an iterative procedure to discover a minimal value of the objective function in order to arrive at the best outcome. Along with a few learning and weighting criteria, the method makes use of parameters including swarm size (N), iteration number (T), and search space dimension (D) [28].

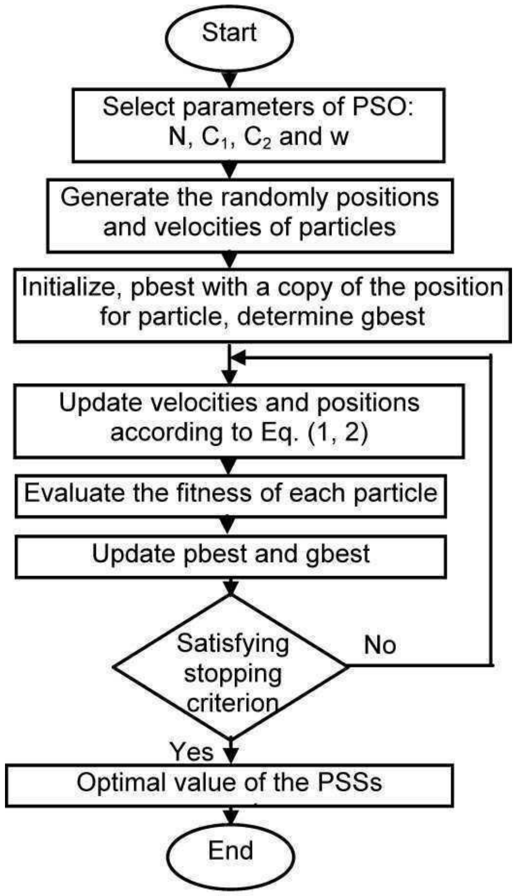


Fig. 3.5 PSO Flowchart

3.2 Block Diagram of the system

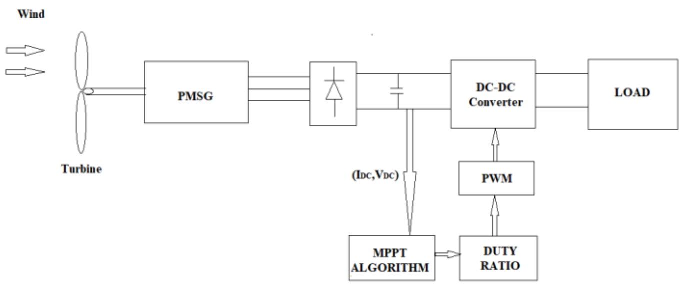


Fig.3.2. Block Diagram of the MPPT based WECS

The above figure 3.2 shows the simple block diagram preferred for this research. As two MPPT methods have been used in the model, the block corresponding to the MPPT algorithm is altered to obtain the different MPPT control.

The MPPT block that I have used for the Perturb and Observe (P&O) method is purely a mathematical one. On the other hand the MPPT algorithm block used for PSO method is a MATLAB compatible PSO code.

IV. Simulation Results

4.1 MPPT-1

4.1.1 PERTURB AND OBSERVE ALGORITHM BASED MPPT WITH CONSTANT WIND SPEED INPUT :

The following is the simulation designed in Simulink:

The input wind speed is kept constant at 12 m/s.

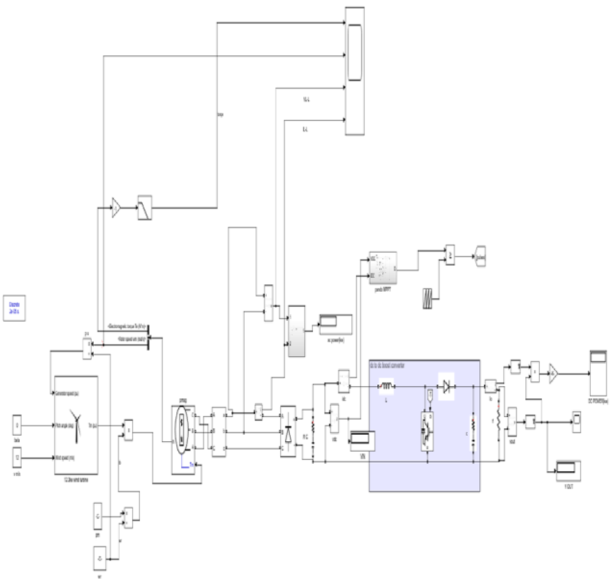


Fig 4.1 Simulation Model

The following is the curve traced by dc power output of the System. As we can see initially the curve is traced upward which signifies that the MPPT is achieved.

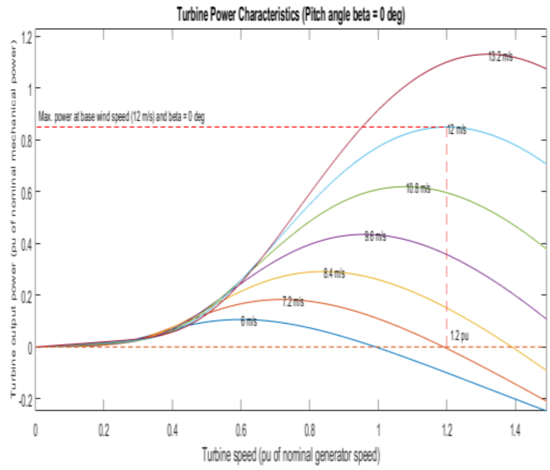


Fig 4.2 Result of wind turbine

4.1.2 PERTURB AND OBSERVE ALGORITHM BASED MPPT WITH STAIRCASE INPUT WIND SPEED:

SIMULATION:-

The constant input in the previous simulation is removed by staircase input in this simulation.

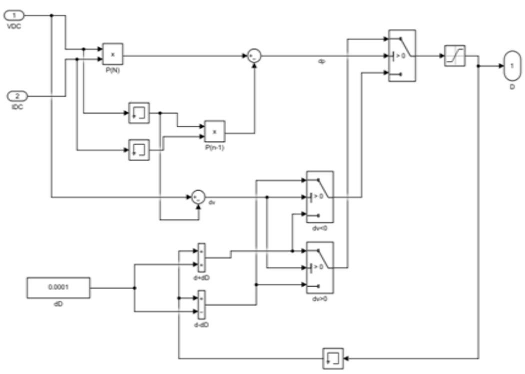


Fig 4.3 P&O MPPT Based WECS

RESULT:

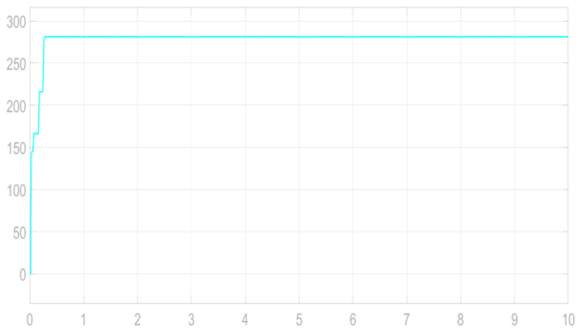


Fig 4.4 Result of DC o/p Voltage

Component of PMSG :

Name	Value
C	6.6094e^-04
D	0.8813
Io	30
Io ripple	0.2
L	4.5573e^-05
Po	12000
RL	13.33
Vinmin	50
Vout	400
Dl	48
Dv	2
Fs	20000
N	0.95

S.No.	R load	V in	V out	Pac	Pdc
1.	13.5	55.87	281.33	7.163	5.863
2.	13.33	-0.17	0.00	0.4375	2.068e^20
3.	54	79.91	398.18	5.918	2.936
4.	56	4.77	0.00	0.4822	0

4.2 MPPT-2

4.2.1 PSO ALGORITHM BASED MPPT WITH STAIRCASE INPUT:

SIMULATION:-

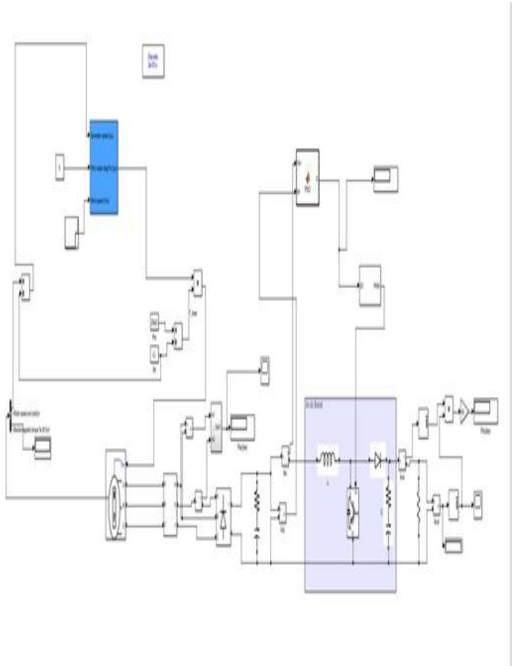


Fig 4.5 PSO MPPT Based WECS

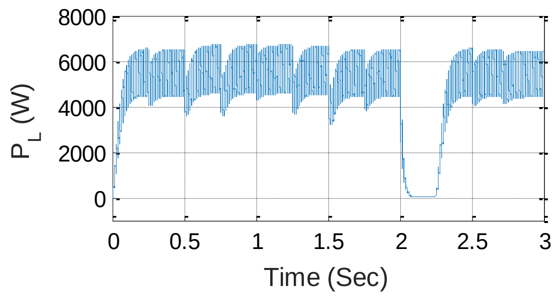


Fig 4.6 Result of DC o/p Power

V. Conclusion

Both MPPT methods—P&O and PSO—have been successful in obtaining the maximum power. In all situations, MPPT is accomplished by adjusting the dc-dc boost converter's duty ratio. The Tip-speed ratio is influenced by the DC/DC control, which also impacts rotor speed. Thus, TSR is kept at a desirable level by regulating the duty ratio. We may thus conclude that tip-speed ratio management has been effective. The WECS system has been designed using the necessary methodology. The simulation was carried out in MATLAB Simulink using both constant and variable input conditions. PSO method has demonstrated superior performance than P&O algorithm because it takes less time to first obtain the MPPT under continuous input.

Additionally, compared to P&O algorithm, PSO has exhibited superior steady state stability. We may also construct WECS in hardware to test its real viability as the simulation of WECS to regulate the TSR was performed in MATLAB Simulink. As was the project's goal, just the Tip-speed ratio is controlled here, but we can also create an appropriate pitch controller for WECS hardware implementation.

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