# Maximum Power Extraction For Hybrid Solar Wind Renewable Energy System Based on Swarm Optimization

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**Abstract-** This paper aims to extract maximum power for a hybrid solar wind renewable energy system using the Particle Swarm Optimization (PSO) for standalone applications. Maximum power extraction based on PSO works to achieve optimal power on HRES by adjusting the duty cycle for the boost converter for each energy source system based on current and voltage measurements. The inverter connects the DC boost and load, and the DC bus voltage is kept constant by the inverter's duty cycle adjustment using PI controller. PSO performance is analyzed through the changes in wind speed and solar irradiation, as maximum power extraction. According to simulation result, PSO can track the maximum power against changes in wind speed and solar irradiation. PSO has a better performance compared to P&O methods, and constant DC bus voltage can be maintained.

**Keywords** Wind Turbine; Photovoltaic; HRES; Maximum Power.

**Nomenclature**

| | | | |
|---|---|---|---|
| PSO | Particle Swarm Optimization | v | Wind speed (m/sec) |
| HRES | Hybrid renewable energy system | Pm | Generated mechanical power |
| PMSG | Permanent magnet synchronous generator | Cp | Turbine power conversion coeficient |
| PI | Propotional integrator | λ | Tip speed ratio |
| P&O | Perturb & Observe | β | Pitch angle |
| PV | Photovoltaic | R | Turbine radius |
| MPP | Maximum power point | Vout | Output voltage of boost converter |
| WTS | Wind turbine system | D | Duty cycle |
| WT | Wind turbine | Vin | Input voltage |
| DC | Direct current | Pout | Output Power |
| $V_{PV}$ | PV output voltage (V) | $R_L$ | Load resistance |
| $I_{PV}$ | PV output current (A) | Rin | Input resistance of boost converter |
| $I_{ph}$ | PV cell phase current (A) | w | Momentum factor |
| η | ideality factor | $K_1$,$K_2$ | Random numbers |
| K | Boltzman constanta | $R_1$,$R_2$ | Acceleration constanta |
| T | Ambient temperature (K) | $D_i^k$ | Present duty cycle |
| $I_{PVrs}$ | Reverse saturation current (A) | $D_i^{k+1}$ | Changed duty cycle |
| q | Electron charge | $D_{Pbesti}^k$ | Best duty cycle for every particle |
| Rs | Series resistance | $\Delta D_i^k$ | Present particle velocity |
| $R_{sh}$ | Shunt resistance | $D_{Gbesti}^k$ | The best duty cycle on group |
| $V_{OC}$ | Open circuit voltage (V) | $\Delta D_i^{k+1}$ | The changed particle velocity |

| | | | |
|---|---|---|---|
| $I_{sc}$ | Short circuit current (A) | $P_{PV}$ | PV output power |
| G | Solar irradiation | $P_{WT}$ | The rectifier output power |
| $G_n$ | Nominal irradiation | $V_{PV}$ | Photovoltaic output voltage |
| Pw | Wind Energy | $V_{WT}$ | Three phase rectifier output voltage |
| ρ | Air density ($Kg/m^3$) | $I_{PV}$ | Photovoltaic output current |
| A | Blade area | $I_{WT}$ | Three phase rectifier output current |

## 1. Introduction

The increasing demand for electricity is currently not proportional to the availability of energy from fossil fuels for electricity generation, requiring the development of energy from renewable energy as an electricity generator [1-3]. wind and solar energy to produce electricity has grown rapidly due to their unlimited availability and lack of pollution. However, this energy source depends greatly on wind speed and the intensity of solar energy, both of which cannot be predicted. As a result, combining several energy sources in one system can overcome a source shortage while also meeting the needs of the load. A HRES is integration various of energy sources that can be used independently or connected with a network. The HRES has the major benefit of achieving higher efficiency than a single power source [4]. To achieve higher efficiency, a controller is required to extract optimum power. Several methods for extracting optimum power from wind and solar hybrid systems have been developed [5].

To convert solar power into electricity, a photovoltaic (PV) is needed. Increased efficiency of the PV system can be achieved if it works at the maximum power point (MPP), so maximum power extraction is required, which will track MPP. Several methods had been used to obtain the maximum power. The perturb and observe (P&O) and incremental conductance have been applied to looking for maximum power without mechanical sensor [6-7]. These methods are simple and easy to apply, but it causes oscillations and yields low accuracy. The adaptive P&O algorithm was developed to enhance upon the fixed P&O method and produce better performance [8-9], but the use of this method results in time varying convergence. The use of neural networks, fuzzy logic, genetic algorithms and swarm algorithm for tracking maximum power in PV has also been used using current and voltage measurements. Based on the simulation results can track the maximum power well, however this method needs a longer convergence time [10-13]. The PSO algorithm was created for PV systems in order to achieve optimal power based on electric parameter, which determine the power generated. According to the results of the experiments, PSO can track the MPP with a faster convergence time than P&O algorithm. [14].

The wind turbine system (WTS) utilizes an electric generator and a converter to convert wind energy to electricity. To increase efficiency, WTS should work at optimum power at any change in wind speed. Optimal torque control and tip Speed ratio are simple methods that have been used to extract MPP in the WTS [15]. This methods have a fast maximum power tracking speed and high performance, but this method requires precise measurement of wind speed and system characteristics, thereby increasing the cost of the system [16]. Several methods have been developed without the use of mechanical sensors. The P&O algorithm is also applied to WTS to achieve MPP using voltage and current measurements in the converter circuit [17]. However, this method is very dependent on the step size determination and produces oscillations. Adaptive P&O was developed by producing step sizes that can change adaptively and produce better performance [18-19]. In addition, the maximum power extraction in WTS has also been developed using artificial intelligence, including using fuzzy logic methods, genetic algorithms, and neural network. These algorithms produce better performance than P&O algorithm, but requires a larger memory [20-24]. PSO optimized maximum power using generated converter power. According to the simulation, the PSO method is successful in maintaining the output power at an optimal value without mechanical sensors or system knowledge. Furthermore, the use of PSO does not result in oscillations around the MPP [25]. PSO is also used to adjust the tuning of the proportional integral controller (PI) which is used to adjust the PMSG speed in WTS. Compared to PI controllers, the use of PSO – PI controllers results in better performance [26].

A HRES has been developed to increase efficiency and power output. One type of HRES that has been widely studied is the solar wind energy system where to get maximum power, maximum power extraction is required. The constant voltage method is used in HRES to obtain a constant voltage on battery charging [27]. However, the use of this method produces large oscillations and requires a long convergence time. The P&O algorithm has been used as an active power control in a HRES and produces good dynamic performance against changes in wind and solar irradiation [28]. P&O modifications carried out by providing step size changes have also been carried out and implemented in the hybrid system [29]. Batteries have also been used as energy storage in a solar wind hybrid system to reduce fluctuations in generated power. The use of batteries can produce stable power at the load despite changes in wind and solar intensity [30]. Incremental conductance is a simple method also used in HRES [31]. In this hybrid system, artificial intelligence in the form of a neural network algorithm and fuzzy logic have been implemented as MPPT, resulting in improved performance [1][5][32-33]. Compared by ANN and fuzzy logic, PSO does not require parameter tuning and has a high tracking speed [31]. PSO has been used in wind and solar hybrid systems to reduce system operational and maintenance costs [34]. In this article, PSO algorithm is developed to optimize maximum power in a standalone hybrid solar-wind renewable energy system. The PSO algorithm produces two duty cycles which are used to activate the boost converter without using a mechanical sensor. The load voltage is maintained constant by adjusting the DC bus voltage connected to the inverter. PSO performance is tested through simulation and compared with P&O algorithm.

## 2. Design of Standalone Hybrid Solar Wind Renewable Energy System

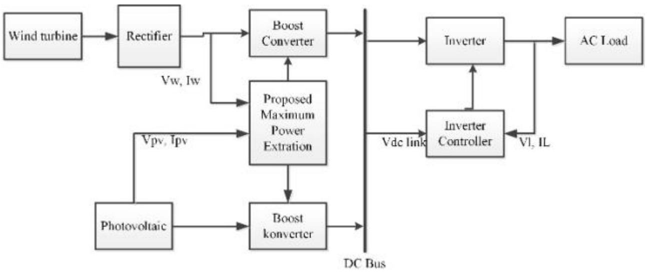



**Fig 1**. The proposed standalone hybrid solar and wind renewable energy system

The proposed HRES system is integration between PV systems and WTS, as shown in Fig 1. The PV system consists of PV and boost converter, while WTS consists of PMSG, three phase rectifier and boost converter. WTS and PV systems are combined via a DC bus. The inverter circuit connects the DC bus to the load. The proposed maximum power extraction using PSO will produce two duty cycles to activate each boost converter in the proposed HRES. Determination of duty cycle based on the generated voltage and current of PV and rectifier. The inverter will be controlled by the inverter controller to produce the AC voltage required by the load. Inverter control based on the PI controller will produce a duty cycle to drive the Voltage source inverter and maintain a constant voltage on the DC bus.

### 2.1. *Photovoltaic Modelling*

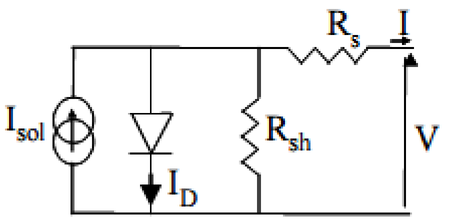



**Fig 2**. Photovoltaic equivalent circuit

Photovoltaic (PV) is an electricity device consisting of multiple cells that converts solar energy into electric power. PV can be modeled as current source and single diode, as shown on Fig 2.

The PV's current and voltage characteristics are used in the mathematical modeling. The relationship between a PV panel's current and output voltage are stated on eq. (1) and (2)

$$V_{PV} = \frac{\eta KT}{q} ln\left(\frac{I_{ph}}{I_{pv}} + 1\right) \quad (1)$$

$$I_{PV} = I_{ph} - I_{PVrs}\left(exp\left(\frac{q(V_{PV}+I_{PV}R_S)}{\eta KT}\right) - 1\right) - \frac{V_{PV}+I_{PV}R_S}{R_{SH}} \quad (2)$$

Series resistance (Rs) dan shunt resistance (Rsh) can be expressed on eq. (3) and (4)

$$R_s = 0.09\,\frac{V_{OC}}{I_{SC}} \quad (3)$$

$$R_{sh} = 11\frac{V_{OC}}{I_{SC}}\frac{G}{G_n} \quad (4)$$

In this paper, standalone HRES is designed using a PV module of the Trina Solar TSM 25PA05 type which has specifications as shown in Table 1.

Tabel 1. Parameter specification of Trina Solar TSM-250PA05 PV Module

| Parameter | Value |
|---|---|
| Maximum Power | 249.86 W |
| Maximum Current | 8.06 A |
| Maximum Voltage | 31 V |
| Open circuit voltage | 37.6V |
| Parallel string | 1 |
| Series connected module per string | 10 |
| Temperature | $25^o$ C |
| Solar irradiation | 1000 W/$m^2$ |

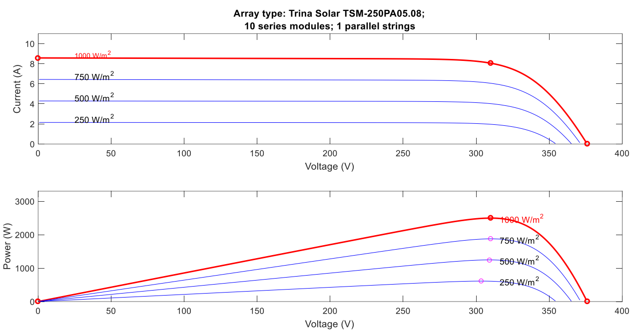



**Fig 3**. Characteristics Curve of Trina Solar TSM-250PA05 PV Module

The PV characteristic curves depend on temperature and solar irradiation that influenced PV generated power, as shown in Fig 3. At certain solar irradiation will produce a certain MPP. A controller is therefore required to extract maximum power at each change in irradiation and temperature.

### 2.2. *Wind Turbine Modelling*

A wind turbine (WT) is made up of a wind turbine and an electric generator. To achieve good and accurate performance, wind turbine modeling is used in the design and development of controls on WTS. Wind energy and mechanical power produced by WTS can be stated on eq. (5) and (6).

$$Pw = \frac{1}{2}\rho A v^3 \quad (5)$$

$$Pm = 0{,}5\pi\rho Cp(\lambda,\beta)R2v3 \quad (6)$$

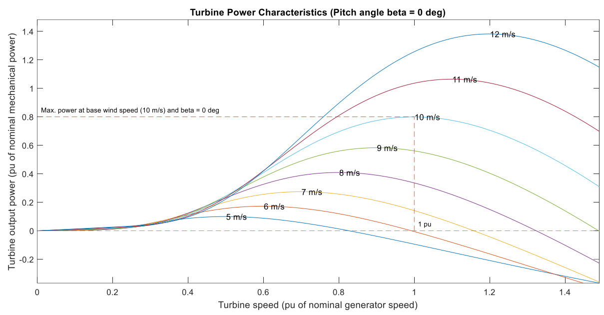



**Fig 4**. Wind Turbine Characteristics Curve.

In this article, the characteristic curve of the 8.5 KW PMSG WTS used is shown in Fig 4. According to the characteristic curve, the wind turbine will produce a different MPP at certain wind speed. The specifications of the wind turbines used are shown in Table 2.

Tabel 2. Parameter spesification PMSG Wind turbine

| Parameter | Values |
|---|---|
| Power (P) | 8500 W |
| Stator phase resistance ($R_s$) | 0.425Ω |
| Inductance ($L_q$ and $L_d$) | 8.3mH |
| Moment inertia | 0.01197 kg/$m^2$ |
| Pole pairs | 4 |
| Rated wind speed | 12m/s |

### 2.3. *Boost Converter*

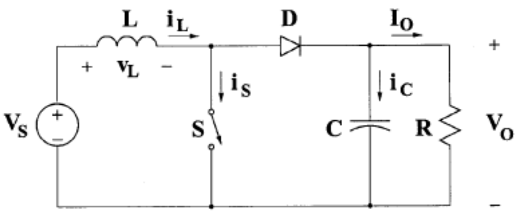



**Fig 5**. Boost Converter Circuit

The boost converter connects the PV and the three phase rectifier of the WTS with the DC bus. The boost converter includes a switching component such as a Mosfet or IGBT, a fast recovery diode, a capacitor and an inductor, as shown in Figure 5. This circuit is widely applied to renewable energy systems, because of its simple structure with the use of fewer components and high conversion efficiency. The duty cycle sent to the switching component determines the voltage generated. The inductor current rises linearly when switching component is turn on and the diode is turn off. On the other hand, diode is active when the switch component is turn off and the inductor is discharged so that current flows to the load. The circuit output voltage (Vout) depends on the operating cycle (D) expressed on eq.(7).

$$V_{out} = \frac{Vin}{1-D} \quad (7)$$

Output power ($P_{out}$) sent to the load ($R_L$) can be expressed on eq. (8)

$$P_{out} = \frac{Vin^2}{(1-D)^2 RL} \quad (8)$$

The output power equals to the input power if the power loss in circuit is very small and very negligible.

$$P_{in} = \frac{V_{dc}^2}{R_{in}} \cong P_{out} = \frac{Vdc^2}{(1-D)^2 RL} \quad (9)$$

Boost converter input resistance ($R_{in}$) can be expressed by

$$R_{in} \approx (1-D)^2 R_L \quad (10)$$

Relationship between output power, input resistance and duty cycle in boost converter can be shown on eq. (9), (10), and (11). A decrease in the duty cycle will increase the input resistance thereby decreasing the input current and electromagnetic torque. PMSG rotor speed increases if the electromagnetic torque is reduced so that the duty cycle setting can be used to adjust the rotor speed and obtain optimal power.

## 3. Maximum Power Extraction Based on PSO

PSO is a swarm intelligence algorithm also known as an algorithm of behavioral inspiration. This algorithm is inspired by birds' behavior and which consists of the actions and influences of others individual within a group. Every individual has two features: position and speed. Each individual moves with a certain speed to achieve the best position against a predetermined objective function. Each particle is associated with the best possible objective function on the path of best position (Pbest). Then its group path becomes the best position for all particles [26][14].

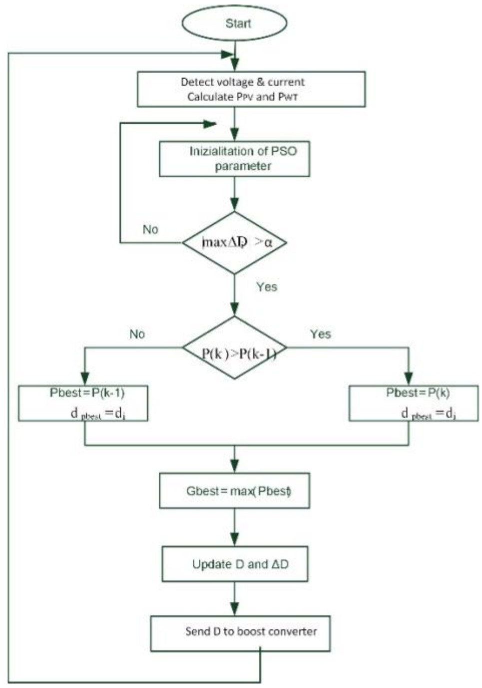



**Fig 6**. PSO Algorithm Flowchart

In this article, PSO is used to optimize the generated power of the proposed HRES. The appropriate duty cycle will be determined by PSO based on the generated voltage and current of the PV and rectifier. The particle position is the duty cycle for each boost converter and duty cycle step size is the particle velocity. The output power of each connected converter with the PV and three-phase rectifier in WTS is the PSO's objective function in this article. The change in duty cycle (ΔD) and duty cycle (D) can be determined by.

$$\Delta D_i^{k+1} = w\,\Delta D_i^{k} + R_1K_1(D_{Pbesti}^{k} - D_i^{k}) + R_2K_2(D_{Gbesti}^{k} - D_i^{k}) \quad (11)$$

$$D_i^{k+1} = D_i^{k} + \Delta D_i^{k} \quad (12)$$

Figure 6 shows the PSO flowchart. In this article, the PSO algorithm produces two duty cycle for the boost converter in proposed HRES , where the stages of the PSO algorithm are:

- Detect output voltage and current at 3 phase rectifier circuit in wind turbine system and PV output.
- Calculate the PV output power ($P_{PV}$) and the three phase rectifier output power ($P_{WT}$) that can be expressed on eq. (13) and (14).
    - $P_{PV} = V_{PV} * I_{PV}$ (13)
    - $P_{WT} = V_{WT} * I_{WT}$ (14)
- Initialization of PSO parameter, particle number = 10, and the maximum step number = 100, w = 0.15, $R_1$ = 0.5, $R_2$ = 0.75, α = 0.001.
- compare the maximum the duty cycle step size with α values, if the step size value exceeds then the PSO parameter must be re-initialized
- Assign the highest generated converter power. If generated converter power is higher than previous one, the best particle value equals generated power, and vice versa
- Select a best swarm value based on a highest value of each particle
- Renew duty cyle and duty cycle step size for every particle based on equation (11) and (12)
- Send duty cycle to boost converter.

## 4. Inverter Controller

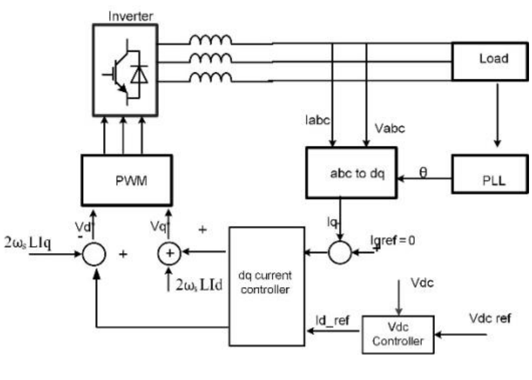
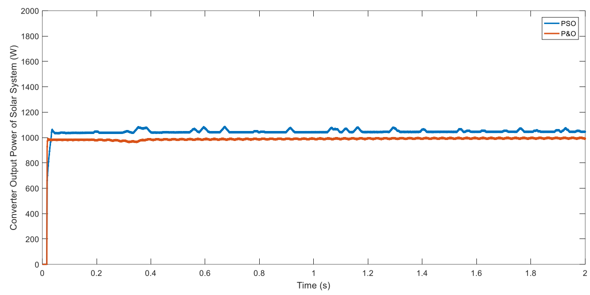


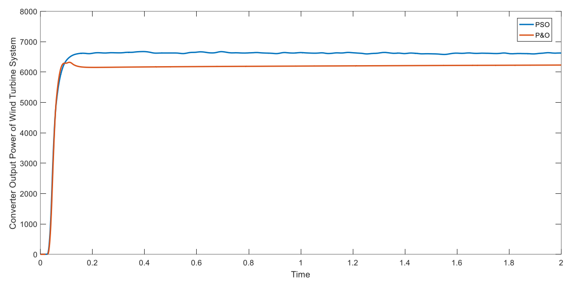

**Fig 7**. Inverter controller

The inverter controller functions to keep the DC bus voltage at 450V, so the constant load voltage was kept at 230V inverter control. Load voltage and current are converted in a dq reference frame. The inverter control consists of a voltage controller and a dq-current controller based on a PI controller, shown in Fig 7. The voltage controller will generate Idref based on the DC bus voltage ($V_{DC}$) and reference voltage. The current controller includes two current controllers $I_d$ and $I_q$ using a PI controller. To obtain a load factor power of one, the $I_{qref}$ value is 0. The voltage controller has a proportional constant ($K_P$) parameter value of 100 and an integrator constant ($K_I$) of 40. While the dq current controller has a $K_P$ parameter value of 0.25 and a $K_I$ of 10.

## 5. Results And Discussion




(a) The PV system converter output power on Irradiance of 600 W/m$^2$

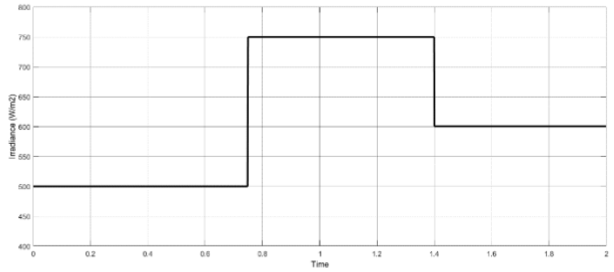



(b) The wind turbine system converter output power on wind speed of 10m/s

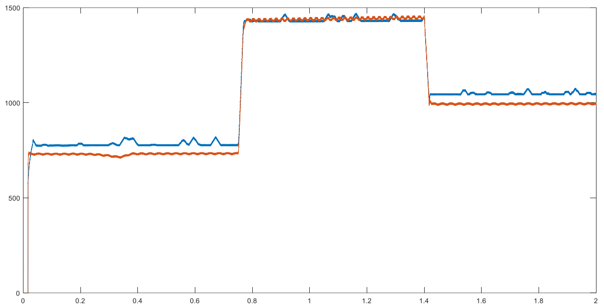
**Fig 8**. The Converter output power on constant irradiance and wind speed

PSO-based maximum power extraction has been applied to a standalone solar wind HRES to obtain MPP. Algorithm performance was tested through simulation with several conditions. PSO performance as the maximum power extraction compared to the P&O method. Fig 8 shows the converter output power in the PV system and WTS when solar irradiation is 600 W/m$^2$ and wind speed is 10m/s. The PV system generates power of 1071 watts, while the P&O method is 987 watts. While WTS produce power equal to 6642 watts and P&O method produce 6497 watts. PSO in a hybrid solar-wind system produces higher power and lower oscillations.

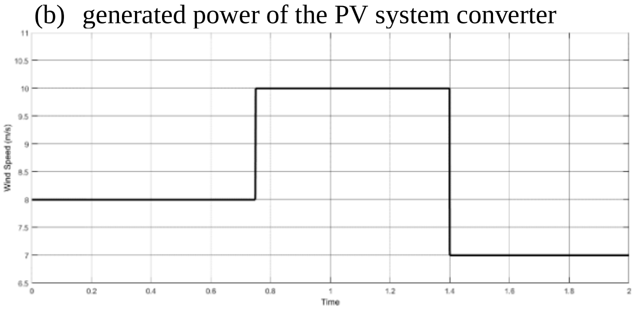
PSO as maximum power extraction in the hybrid solar wind system was also tested by providing changes in irradiation and wind speed. As shown in Fig 9a, solar irradiation changes under three conditions as well as changes in wind speed, as shown in Fig 9C. The generated power of the PV system is shown in Fig 9b, while the generated power of WTS is shown in Fig 9d. The PSO and P&O algorithm can follow changes in wind speed and irradiation and obtain the maximum power at each of these changes. At 500 W/m$^2$ irradiation, PSO produces a converter output power of 878 Watts, while the P&O method only produces 734 Watts. While at 750W/m$^2$ irradiation, PSO and P&O produce almost the same output power, but the P&O method produces larger oscillations. At a wind speed of 8m/s, WTS produces 5644 Watts of power while the P&O method is 5627 Watts. The use of PSO produces more power and faster transient time than the P&O method.



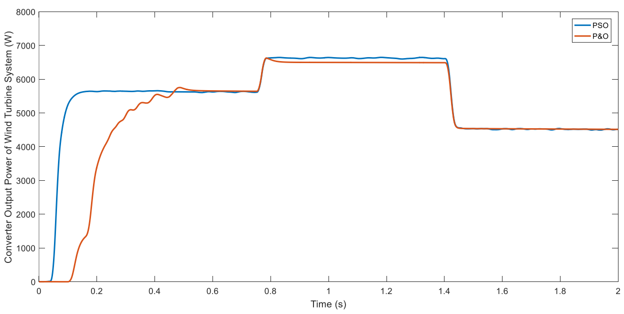

(a) The Irradiance change



(b) generated power of the PV system converter




(c) The wind speed change




(d) Generated power of the wind turbine system converter

**Fig 9**. Generated power of the hybrid wind solar converter with changed irradiance and wind speed

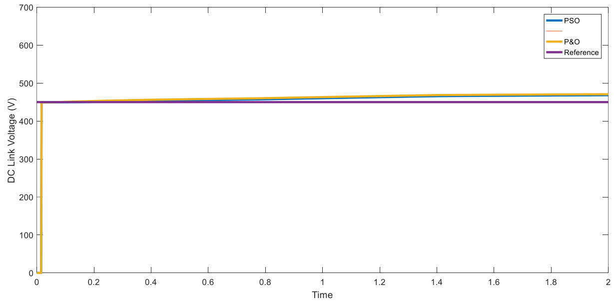



**Fig 10**. DC bus voltage on changed irradiance and wind speed

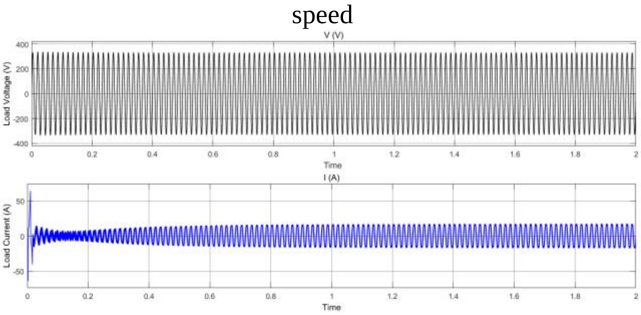



**Fig 11**. Load voltage and current on changed irradiance and wind speed

Figure 10 shows the DC bus voltage when given changes in wind speed and irradiation. The inverter controller can achieve a constant DC bus voltage of 450V. At changes in wind speed and high irradiation there is a maximum error of 4%. By making the DC bus voltage constant, the AC voltage and current received by the load can be maintained constant as well, as shown in Fig 11.

## 6. Conclusion

The standalone hybrid solar-wind renewable energy system with maximum power extraction based on PSO has been described in this article. The HRES consists of a 2.5kW PV system and an 8.5 kW PMSG wind turbine with duty cycle settings on the boost converter to obtain MPP from both sources. According to the simulation results, the hybrid system produces power of 1071 Watt and 6642 Watt respectively at 600 W/m2 irradiation and 10m/s2 wind speed. When given changes in wind and solar irradiation, maximum power extraction with PSO can track the maximum power following these changes. The DC bus voltage can be maintained constant at 450V through inverter control despite changes in wind speed and solar irradiation. Compared to the P&O algorithm, the PSO produces more power and less oscillations so that it has better performance. Future work this algorithm will be developed to implement on the prototype of small-scale solar wind renewable energy system in off-grid application.

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