International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 3, September 2017, pp. 1359~1367
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i3.pp1359-1367

High Performance Maximum Power Point Tracking on Wind Energy Conversion System

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Article Info

Article history:

Received Mar 10, 2017
Revised Jul 21, 2017
Accepted Aug 1, 2017

Keyword:

Buck converter
Firefly algorithm
Maximum power
Tracking
Wind energy

ABSTRACT

This paper presents the maximum power point tracking (MPPT) to extract the power of wind energy conversion system (WECS) using the Firefly Algorithm (FA) algorithm. This paper aims to present the FA as one of the accurate algorithms in MPPT techniques. Recently, researchers tend to apply the MPPT digital technique with the P n O algorithm to track MPP. On the other hand, this Paper implements the FA included in the digital classification to improve the performance of the MPPT technique. Therefore, the FA tracking results are verified with P n O to show the accuracy of the MPPT algorithm. The results obtained show that performance is higher when using the FA algorithm.

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1. INTRODUCTION

The utilization of wind energy as a source of renewable energy increased significantly in the 20th century. Its energy supply of the world's energy is targeted to increase from 2.6% in 2014 to 18% in 2035 [1]. That is what spur of the development of wind energy utilization and pursued through the the use of wind energy technology development WECS (Wind Energy Conversion System) [1].

The accuracy of obtaining maximum power point (MPP) is a key of the success of WECS technology. Therefore, Wind Turbines (WTs) must operate in their MPP despite wind speed changes, in order for WECS to always generate maximum power [2],

Figure *1* (a). Figure 1 shows that MPP is achieved on a particular rotor speed for each wind speed. To track this MPP, a control scheme called Maximum Power Point Tracking (MPPT) has been widely used [3]. MPPT technology controls WTs to generate power as much as possible in the region between the cut-in speed (Vcut-in) and the rated speed (Vrated),

Figure *1*(b) [2].

The MPPT control technique algorithm is divided into two categories: techniques with knowledge of turbine characteristics and without knowledge of turbine characteristics [4]. The later methods don't require the mechanical sensors, so they are more reliable and low-cost [5]. This method obtains MPP by monitoring the power taken from the value of the different wind speed.

To realize the MPPT techniques above, the power converter is used as a liaison between the load and the WT that functions as a transferring maximum power from WECS to load. The electric parameters that are controlled on the MPPT methods: voltage, current or duty cycle converter. The duty cycle control is more commonly applied, because it is better guarantee the stability of the system [6]. With these considerations, this paper applies duty cycle control.

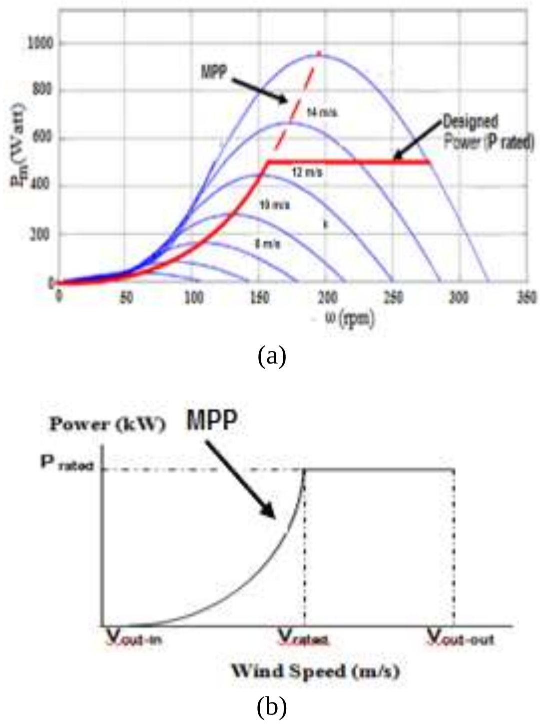


Figure 1. MPP on the Wind Turbine mechanical power as a function of rotor speed for different wind speeds (a), the characteristic of Wind Turbines under various wind speeds (b)

In addition to power converters, the application of the duty cycle control requires optimization techniques with its various algorithms. Algorithms commonly used to get MPP are digital algorithms, such as HC (Hill Climb), AI (Artificial Intelligent), iterative in nature (IN) algorithm [7].

P n O which is the HC algorithm is the mostly widely reported MPPT techniques. One of the most widely used techniques in MPPT is P nO due to its simple and easily implementation [8]-[9]. Furthermore, P n O is slow in rapidly changing conditions and confronts a problem of oscillations around the MPP, so it can be a problem in achieving maximum power point under rapid wind variations [10]. This is why P n O is less appropriate for MPPT technique in WECS.

In the present study, the IN algorithm was developed as an algorithm for MPPT techniques. IN which is Soft computing techniques are fast and efficient, seems to perform better on the execute time to convergence to the optimum [11]. Two types of IN called Particle Swarm Optimization (PSO) and FA were devised to find optimal solutions of noisy non-linear continuous mathematical models. The performance of both algorithms PSO and FA seems to be not so different to approach to the optimum. FA tends to be better, especially on the functions having multi-peaks [11]. They have also simple computation, fast convergence and can be implemented in low cost microprocessor [12] [13]. Taking into account the superiority of the FA, this paper investigates the FA on MPPT techniques from WECS. It has been compared with perturb and observe (PnO) to show its accuracy in tracking MPP.

2. PROPOSED METHODS

2.1. Modeling of Wind Energy Conversion System (WECS)

To investigate the performance of the proposed schemes using FA, a simulation model of WECS consists of Wind Turbine (WT), PMSG (Permanent Magnet Synchronous Generator), Rectifier, DC-DC Buck converter, and the load resistance. Wind power is converted into the the mechanical power by wind turbines, which drives a generator to create the electrical power. The mechanical power (P_m) and the output electrical power (P_e) available from WT can be expressed [5]:

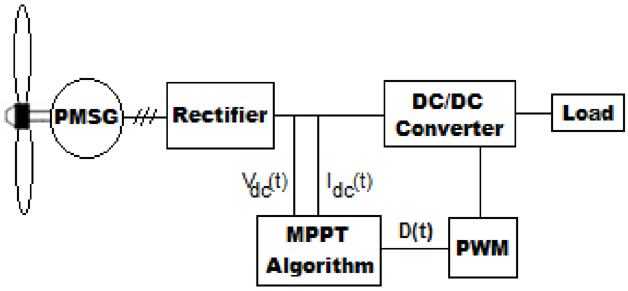


Figure 2. Scheme of the proposed WECS and MPPT control Method

$$P_m = ½ C_p\rho AV^3 \tag{1}$$

$$P_e = P_m . \eta_g \tag{2}$$

C_p is the power coefficient of the blade, ρ is air density (kg / m3), A is the sweep area of the wind turbine rotor Radius = πR^2 (m^2), R is radius turbine, V is wind speed (m/s), η_g is efficiency Generator.

2.2. The Modeling of MPPT

In order to extract maximum energy, the PMSG rotational speed has to be controlled accordingly by means of DC/DC converter with MPPT algorithm. Output power was maximized without any information of turbine parameters by iteratively changing the control variable which results in PMSG rotational speed adjustment [14] the algorithm takes the power of PMSG and the duty cycle of DC/DC converter. The method is based on the fact that at maximum power point [15] for a given wind velocity

$$\frac{\Delta P}{\Delta \omega} = 0 \tag{3}$$

It can be proven that for a buck converter condition is also satisfied by

$$\frac{\Delta P}{\Delta D} = 0 \tag{4}$$

where D is the dc/dc converter duty cycle, and ω is rotor speed WT.

All algorithms on this method, requires only power measurement. P is calculated per cycle. To achieve condition (4), the actual derivative sign has to be evaluated. Therefore, the algorithm presents information about the changes and the last search direction of power and duty cycle. The algorithm generates a duty cycle in response to difference the power of the present and the previous [16]. The previous and the present of power is compared. If the previous power is greater means the result tends to direct the operating point toward MPP, and vice versa. The process continues until the MPP is reached. Therefore, in accordance with the discrete implementation of the method, the method has been classified as digital MPPT. MPP search mechanism of P n O and FA is based on this method, so both of these methods are digital MPPT.

2.3 The MPPT Control Techniques

The principle of the two control algorithms in this paper is a search-remember-reuse. They use memory to store peak power points, which are obtained during the process and are used to track the maximum power point. It starts with a blank memory and during the search execution gradually approaches the determined power difference limit [15]. Referring to Equations 3 and 4, the P n O algorithm uses the following formulation to solve the MPP problem with the converter duty cycle as the control variable: [15]

$$D_k = D_{k-1} + C_1 \frac{\Delta P_{k-1}}{\Delta D_{k-1}} \tag{5}$$

Furthermore, the FA is used to solve the MPP problems. If the control variable (duty cycle converter) is positioned as a firefly. Then some fireflies are released will look brighter and less light which indicates the amount of power generated with a certain duty cycle. The less bright will approach the firmer fireflies, and the brightest present MPP. The basic motion of this firefly switches using the basic algorithm algorithm Firefly (6) [12].

$$x_{i+1} = x_i + \beta_o e^{-\gamma r^2}(x_j - x_i) + \propto \varepsilon_i \tag{6}$$

x_i and x_j represent the position of less bright firefly i and brighter firefly j. β_0 is firefly attractiveness factor , γ is random vector, α is light absorption coefficient, and the vector εi is a random vector generated from a Gaussian distribution [13]. The value of the duty cycle between 0 to 1 indicates the range of positions of the fireflies as control variables is very narrow, so that α and γ can be ignored. This algorithm is called the simply FA. For the simply FA, Equation (6) can be expressed as:

$$x_{i+1} = x_i + \beta_o(x_j - x_i) \tag{7}$$

Equation 6 adapted for duty cycle as a control variable in an attempt to reach the MPP, be:

$$D_{i+1} = D_i + \beta_o(D_j - D_i) \tag{8}$$

D_{i+1} and D_i are the duty cycle at $i+1$ and i sample instant, D_i and D_j represent duty cycle at the less power and duty cycle at the largest power. β_0 is firefly attractiveness factor. Since the methods FA and P n O are identical, then Equation (8) is identical with Equation 5. The proposed MPPT consists of a controller with FA which allows for simultaneous control the duty cycle of the DC-DC Buck Converter, as described in Figure *2*. The control algorithm uses only the dc-link voltage $V_{dc}(t)$ and the dc-current $I_{dc}(t)$ measurements to adjust the duty cycle D(t) directly.

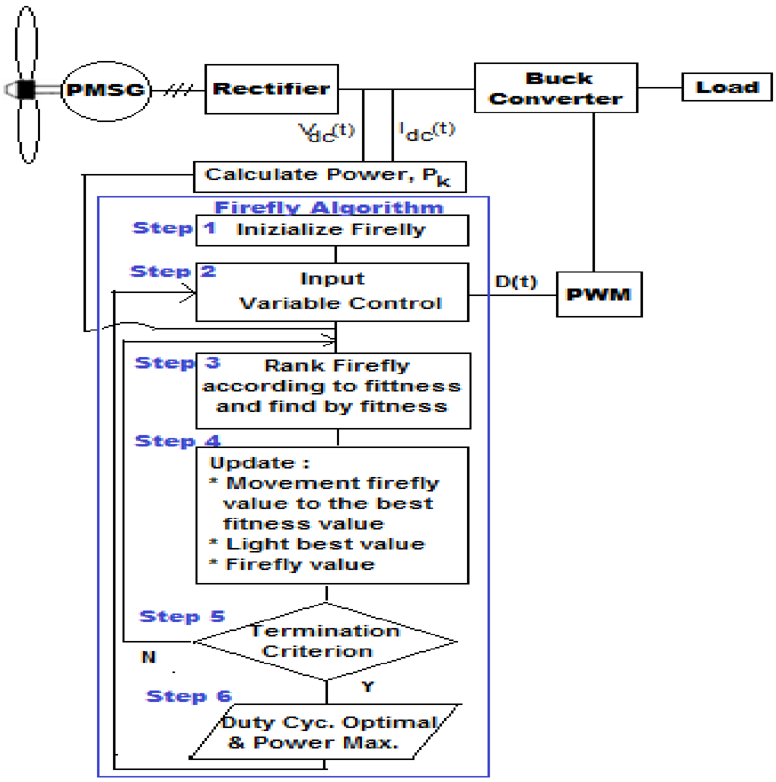


Figure 3. Flow chart the firefly algorithm as MPPT control techniques

2.4. The Firefly Algorithm MPPT

The steps of the FA control method in order to get the maximum power that is: Parameter Setting, Initialization of Firefly, Brightness Evaluation, Update the position of fireflies, Terminate the program, and renitiate the FA. The 6 steps seperti dalam flow chart Figure 3 are described below [12] :

a. Step 1 : Determining the number of firefly, the constants of the FA and the convergence criteria. In this case are set: three fireflies. Furthermore, the termination criterion i.e Maximum of iteration = 10 or the distance among D_j and D_k = 0.001
b. Step 2 : The duty cycles are placed among D_{min} and D_{max} (0 - 1) which is the values of allowable solutions. Its initial values (duty cycle) have been selected manually (D_{i1}= 0.5; D_{i2}= 0.15; D_{i3} = 0.3).
c. Step 3: MPPT control system is operated correspondingly to the each duty cycle sequentially. The initial value of D (D_{i1}, D_{i2}, D_{i3})generated the brightness (P_1, P_2, dan P_3)
d. Step 4 : The duty cycle with maximum power remains in its position and the remaining duty cycle update their position based on :

$$
\begin{aligned}
&\textit{If } P_1 \geq P_2 \textit{ and } P_1 \geq P_3 \\
&\quad \textit{then } D_{i2+1} = D_{i2} + \beta_o\,(D_{i1} - D_{i2}) \\
&\qquad D_{i3+1} = D_{i3} + \beta_o\,(D_{i1} - D_{i3}); \\
&\textit{Else if } P_2 \geq P_3 \textit{ and } P_2 \geq P_1 \\
&\quad \textit{then } D_{i1+1} = D_{i1} + \beta_o\,(D_{i2} - D_{i1}) \\
&\qquad D_{i3+1} = D_{i3} + \beta_o\,(D_{i2} - D_{i3}); \\
&\textit{Else } D_{i1+1} = D_{i1} + \beta_o\,(D_{i3} - D_{i1}) \\
&\quad D_{k2} = D_{k2-1} + \beta_o\,(D_{i3} - D_{i2})
\end{aligned}
$$

e. Step 5 : The step 3-4 will be repeated until the termination criterion is reached.
f. Step 6 : If the wind speed changes, which is detected by sensing the change in the power output, then return to step 2

Subsequently, the P n O algorithm was also placed on the MPPT algorithm, and the simulation results are used to verify the results of MPPT with FA.

3. RESULTS AND DISCUSSION

The following simulation were presented for different wind speed 8, 12 and 14 m/s. The Buck Converter and WG parameters are shown in Table 1 and Table 2. As previously stated that this paper applies The Simply FA, so that α and γ are not taken into account. The optimization results are determined solely by the parameter β to obtain optimal duty cycle.

Table 1. Parameter of Buck Converter

Parameter	Value
Input Voltage	50-100V
Output Voltage	5-25 V
Rated Power	500 W
Switching frequency, f	10 k

The initial position of fireflies as the duty cycle value is manually selected. These duty cycle values produce initial power which may be MPP at certain wind speeds on WT. Iteration continues until the termination criteria are reached as in step 5 above. When termination is achieved, optimum duty cycle value is obtained with its MPP value.

Table 2. Parameter of Wind Generator

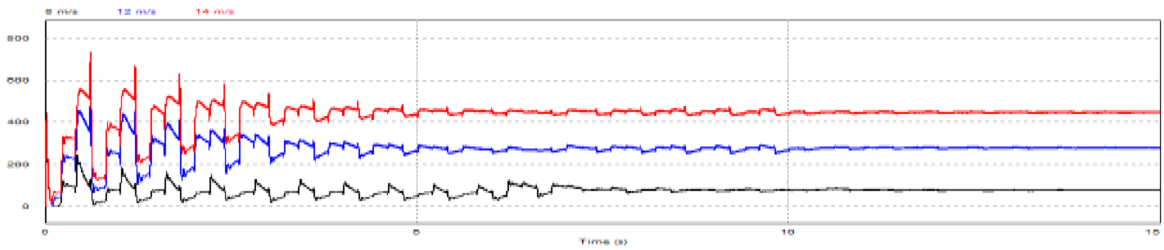
Parameter	Value
Nominal Output Power	500Wp
Base Wind Speed	14 m/s
Base Rotational Speed	250 rpm
Moment of inertia	0.1

The simulation is done by different wind speed and firefly attractiveness factor (*β*) for simulation time 15 sec. Table 3 shows the electric power in a variation of velocity and β value. MPP simulated results for each wind speed are marked by the blocks in Table 3. For different wind speeds, MPP is not achieved at the same β nor at the largest β. The influence of parameter β is further shown in Figure 4. They shows that the greater the β, faster convergence, but not necessarily accurate. Accurate means closer to the value of the MPP.

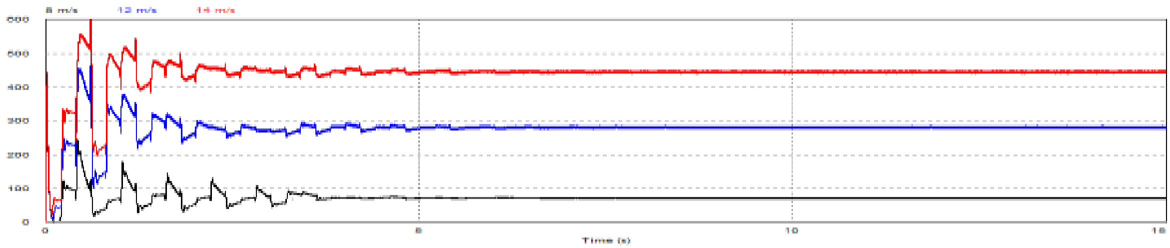
Table 3. Power of WECS dengan variasi kecepatan angin dan firefly attractiveness factor

Wind Speed (m/s)	Power (Watt)				
	β = 0.2	β = 0.4	β = 0.5	β = 0.6	β = 0.8
8	8.022605E+01	8.091640E+01	8.124846E+01	8.524282E+01	8.146482E+01
12	2.719942E+02	2.807526E+02	2.719925E+02	2.696837E+02	2.780621E+02
14	4.227134E+02	4.415815E+02	4.437123E+02	4.311007E+02	4.403684E+02

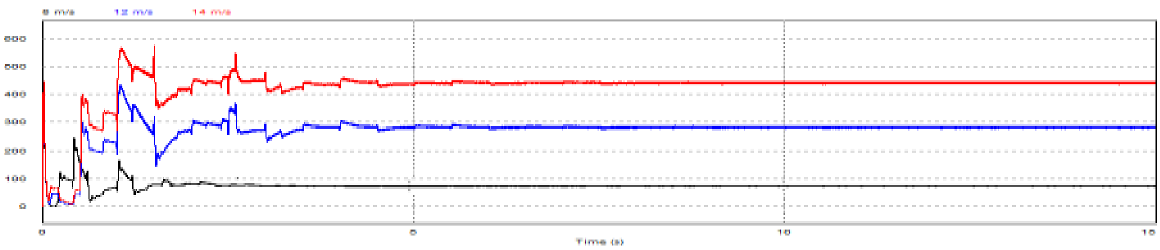
Furthermore, the P n O algorithm was also implemented and tested for the same wind speed and load conditions. Results are presented in Figure 6. It is used to verify the result of applied FA algorithm. Table 4 show the simulation results of WECS power at MPP at varying wind speeds which is tracked by FA and P n O controllers. The value of power tracked, tracking speed, maximum power, steady state ripple and tracking efficiency are also shown. It is observed that FA is faster, higher efficiency, and stable than P n O to track maximum power.



(a)

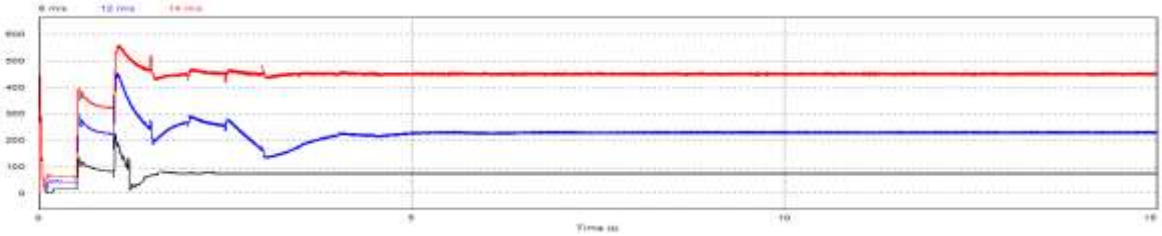


(b)

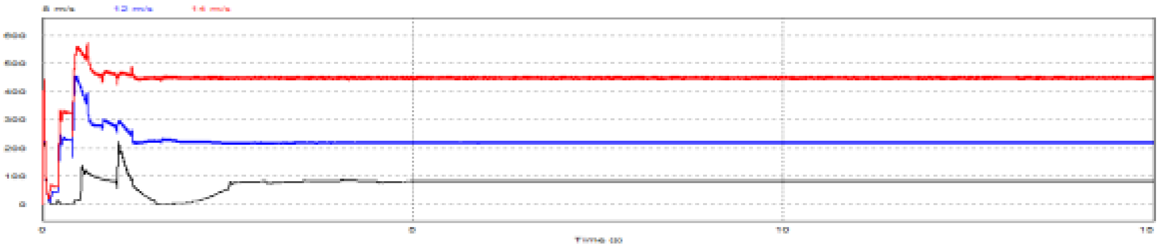


(c)

Figure 4. Simulation result of the WECS pada saat wind speed 8, 12, 14 m/s with β = 0.2 (a), 0.4 (b), 0.5 (c), 0.6 (d), 0.8 (e)



(d)



(e)

Figure 5. Simulation result of the WECS pada saat wind speed 8, 12, 14 m/s with β = 0.2 (a), 0.4 (b), 0.5 (c), 0.6 (d), 0.8 (e)

In comparison, The P n O is slower to convergence and there is much ripple when output power reaches steady state level. Consequently, the FA is more appropriately used to adjust the relatively wind speed changes in WECS.

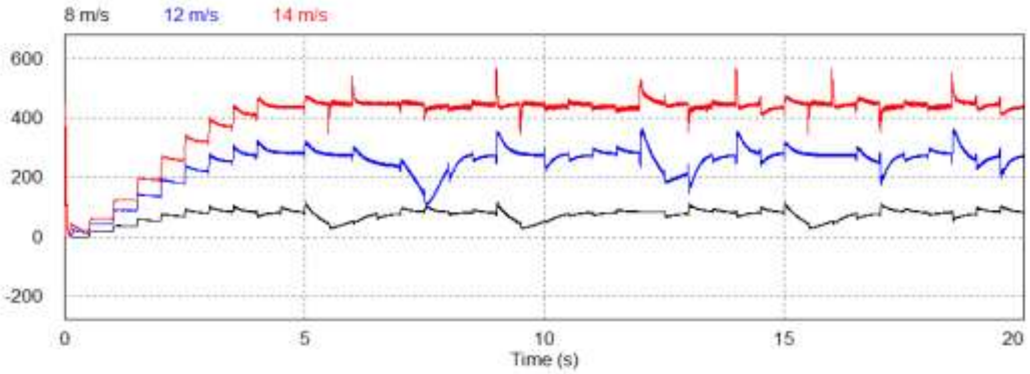


Figure 6. The Result simulation dengan P n O algorithm

Table 4. Comparison of MPPT performance by the simply FA dan P n O

Wind Speed (m/s)	MPPT Control Method	Power Tracked (W)	Tracking Speed (s)	Maximum Power (W)	Steady State Ripple	Tracking efficiency (%)
8	FA	85.242815	1.76	92.16	Minimum	92.49
	P n O	76.205876	4.39	92.16	over	82.69
12	FA	280.752560	4.92	311.04	Avarage	90.26
	P n O	257.37991	4.12	311.04	Over	82.75
14	FA	443.71233	4.54	493.92	Average	89.83
	P n O	433.78427	4.09	493.92	Over	87.82

4. CONCLUSION

Various techniques of MPPT are selected and applied in accordance with the limits and certain conditions. This paper can be a reference for researchers who apply the MPPT on WECS. In comparison, the application of the Firefly Algorithm on MPPT control can reduce the ripple when the output power reaches the steady state level compared to the algorithm P n O.

In addition, the Firefly Algorithm methods used in the design of WECS, increases the efficiency of energy conversion indicate by relatively higher efficiency than the P n O. Efficiencies that can be achieved with the FA method on average of 90%. The FA technique gives better and more reliable control for the WECS application.

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