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Optimized Control and Sizing of Standalone PV-Wind Energy Conversion System

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Abstract

This paper presents an advanced optimization method for a PV-Wind energy conversion system. This method is based on the use of an advanced control strategies of the DC-DC and AC-DC regulator in PV-Wind standalone system. Within this topology a fuzzy logic control is applied to extract the maximum power point of the photovoltaic generator (PVG) and the wind generator (WG). Consequently an optimal sizing of the system by reducing their total cost is designed.

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*Keywords:*Fuzzy logic, maximum power, optimal sizing, standalone PV-Wind system.

1. Introduction

Current researches are focused on the electrical production using multi-sources energy conversion systems [1,2]. Photovoltaic generators (PVG) have maximum power points (MPP) corresponding to meteorological conditions, cell area and load [3]. In Wind generator (WG) when the wind speed varies considerably, the variable speed generation (VSG) is more noticeable than fixed speed systems [4,5]. In these systems, a maximum power point tracking (MPPT) adjusts the system's quantity to maximize turbine power output [6,7]. In PV-Wind stand-alone systems, MPPT algorithms are usually implemented on both DC-DC and AC-DC converters, while battery banks are required to store

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surplus energy, as shown in Fig.1 [8]. MPPT methods can be classified into conventional and advanced methods [9,10]. The conventional methods, require a prior knowledge of the characteristic of the system, or are based on mathematical relationship which does not meet all meteorological conditions. Therefore, they cannot precisely track the MPP of PV generator or the Wind generator at any at any meteorological conditions [9]. Intelligent MPPT methods (i.e. fuzzy logic (FL) and artificial neural networks (ANN) are more efficient, but they are more complex compared to the conventional techniques that are generally simple, cheap and less efficient [11,12]. In this paper an alternative approach has been proposed using optimized Fuzzy Logic controllers to control the PV-Wind system. The main objective of this work is to propose fuzzy controller schemes for maximum power capture of both PV and Wind generators. This paper is organized as follows. Section 2, briefly presents the model of the PVG and WG, section 3, presents a background on maximum power extraction for both systems. Section 4, presents simulation results, section 5 a proposed method for an optimized sizing and, section6 concludes the paper.

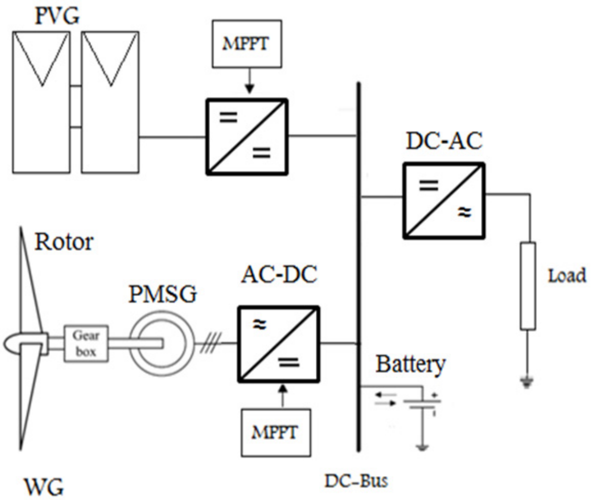


Fig. 1. The standalone PV-Wind hybrid system

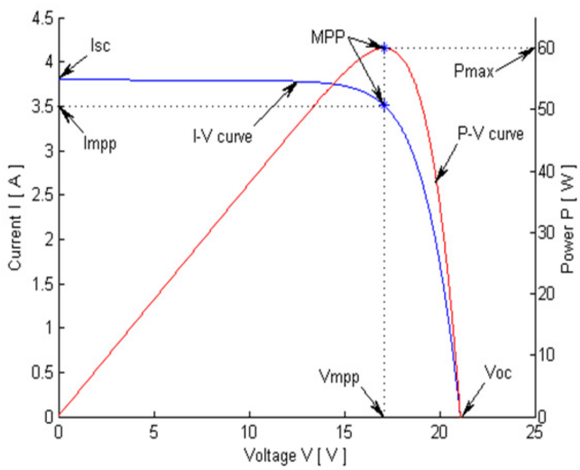


Fig. 2. I–V and P–V characteristics of a PVG.

2. Photovoltaic and wind generators modeling

2.1. Photovoltaic generator model

A single diode equivalent circuit of a PV solar cell is shown in Fig. 2a. The relationship between the cell terminal current and voltage is represented by Eq. (1), [15]:

$$I = I_{ph} - I_o \left[\exp\left(\frac{V + I \cdot R_S}{a \cdot V_{th}} \right) - 1 \right] - \frac{V + I \cdot R_S}{R_P} \tag{1}$$

Where V_{th} is the thermal voltage of the cell, I_{ph} is the photocurrent, it depends mainly on the radiation and cell's temperature. I_o is the saturation current. Fig. 2 shows the I-V and P-V characteristic of the PV module at a fixed cell temperature T and at a certain solar radiation, G. In this figure (I-V curve), there are three key points: The short circuit point ($0, I_{sc}$), the open circuit point ($V_{oc}, 0$), and the maximum power point, MPP (V_{mpp}, I_{mpp}): at this point, the PV module operates at maximum efficiency and produces its maximum power given by:

$$P_{max} = V_{mpp} \cdot I_{mpp} \tag{2}$$

Where I_{mpp} and V_{mpp} are the optimal operating current and voltage respectively. Therefore, it is very important to ensure that the module operates at maximum efficiency to remedy the inherent low efficiency [15]. In order to overcome this problem, specific circuits, called maximum power point trackers (MPPT), are used [13]. Typically, the

MPPT is achieved by interposing a DC-DC converter between the PV array and the load, thus, from the voltage and/or current measurements, the MPPT algorithm generates the optimal duty ratio (*D*) in order to ensure maximum power point tracking.

2.2. Wind generator model

The extracted power is expressed by Eq. (3), [17]:

$$P_{\max} = \frac{1}{2} C_p(\lambda, \beta) \rho \pi R^2 V_{wind}^3 \tag{3}$$

$C_P(\lambda, \beta)$ Is power coefficient, expresses the aerodynamic efficiency of the turbine. With β is the orientation angle of the blades, so the ratio λ can be expressed by the following equation$\lambda = (\Omega_t * R)/V$.

The maximum power from wind energy, for$t = 0.81, \beta = 0$ that gives$C_P = 0.47$, that allows adjusting the torque of the turbine, so as to set its speed to its reference written by: $\Omega_{tref} = \lambda_{opt} * V_{Wind}/R$, it is very important to note that the turbine is to be used in the three zones of operation, Fig.3. Zone I when the wind speed is less than a boot speed, the turbine is stopped. Zone II, in this zone, the power is proportional to the cube of the wind speed. Zone III As from the rated speed, Once the maximum speed reached it is dangerous to let the wind turn [20,21] mechanical braking systems, often a disc brake are active to completely stop the turbine. To ensure maximum turbine efficiency, maintain the coefficient power at its maximum [22].

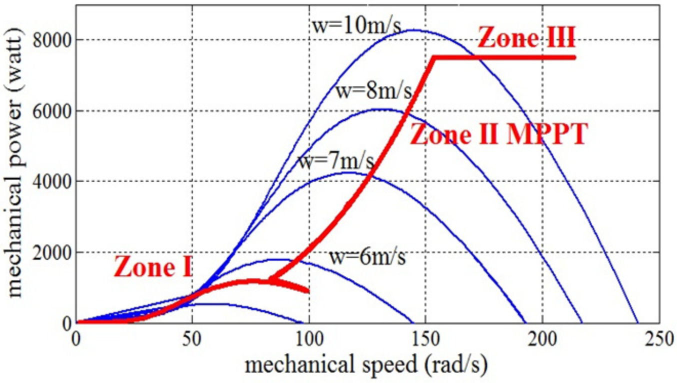


Fig. 3. Typical curve of the extracted power according to the wind speed

3. Fuzzy logic control for PV and wind subsystems

3.1. Fuzzy logic MPPT controller to PV generator

The input variables of proposed controller are an error (*E*) and a change in error (*CE*). At a sampling instant k, these variables are expressed as follows [9,20,21]:

$$\begin{cases} E(k) = \dfrac{P(k) - P(k-1)}{I(k) - I(k-1)} \\ CE(k) = E(k) - E(k-1) \end{cases} \tag{4}$$

Where *P(k)* and *I(k)* are the power and current of the PV array, respectively. The change in duty ratio (Δ*D*) of a DC-DC converter is used as an output. These variables are expressed in terms of linguistic variables such as *PB* (positive big), *PS* (positive small), *Z0* (zero), *NS* (negative small), *NB* (negative big) using basic fuzzy subsets. Fig.4 shows the membership functions for input and output variables. In this paper, the inference method of Mamdani [22], which is the Max-Min fuzzy combination, is used. Table 1 shows the rule table of a fuzzy controller, where all the entries of the matrix are fuzzy sets of error (*E*), change of error (*CE*) and change of duty ratio (Δ*D*) to the converter. The fuzzy rules shown in Table 3 are employed for controlling the DC-DC converter such as the maximum power of the PV generator is reached. As an example, the rule in Table 1: IF *E* is *PB* and *CE* is Z0 THEN Δ*D* is *PB*. This implies that "if operating point is distant from maximum power point towards left hand side and the change of slope in P-V characteristic is about zero, increase duty ratio largely. Given that DC-DC converter requires a precise control signal *D* at its entry, it is necessary to transform this fuzzy information into deterministic information, this transformation is called defuzzification. Some methods for defuzzification are the center of area (COA), Mean of Maxima (MOM), and Max Criterion Method (MCM). In this paper, the center of average (COA) defuzzification is used. The final combined fuzzy set is defined by the union of all rule output fuzzy sets using the maximum aggregation method [22,23]. Thus, the change of duty ratio Δ*D* is determined by the COA method as defined in Eq. (5):

$$\Delta D(k) = \frac{\sum_{j=1}^{n} \mu\left(\Delta D_j(k)\right) \cdot \Delta D_j(k)}{\sum_{j=1}^{n} \mu\left(\Delta D_j(k)\right)} \tag{5}$$

The output of fuzzy logic controller is the change of duty ratio Δ*D (k)*, which is converted to the duty ratio *D (k)* as in Eq. (6):

$$D(k) = D(k-1) + \Delta D(k) \tag{6}$$

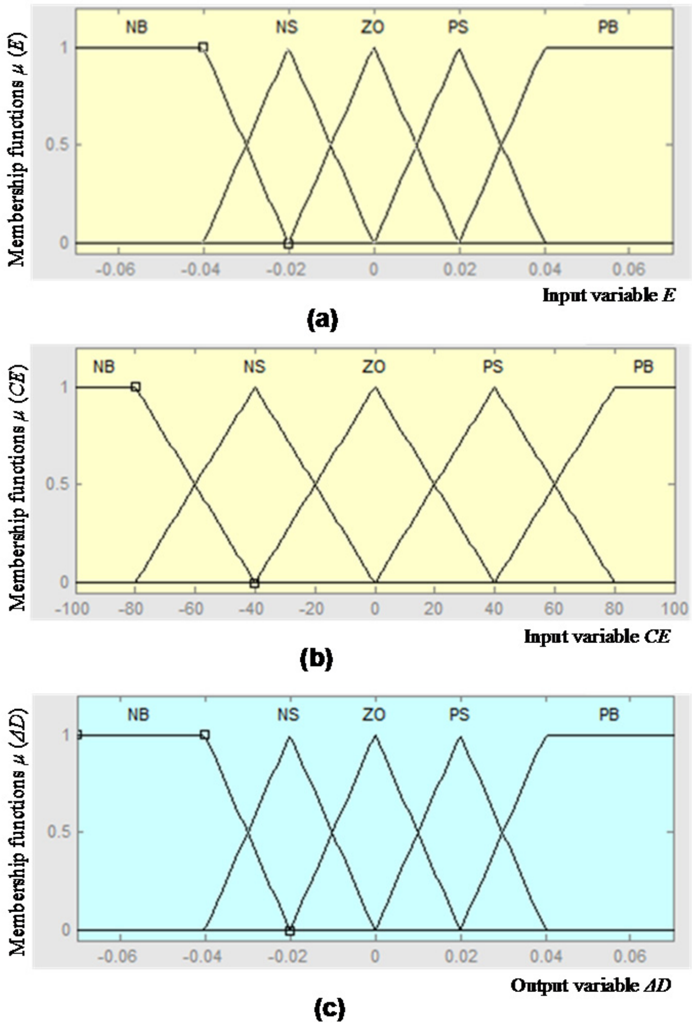


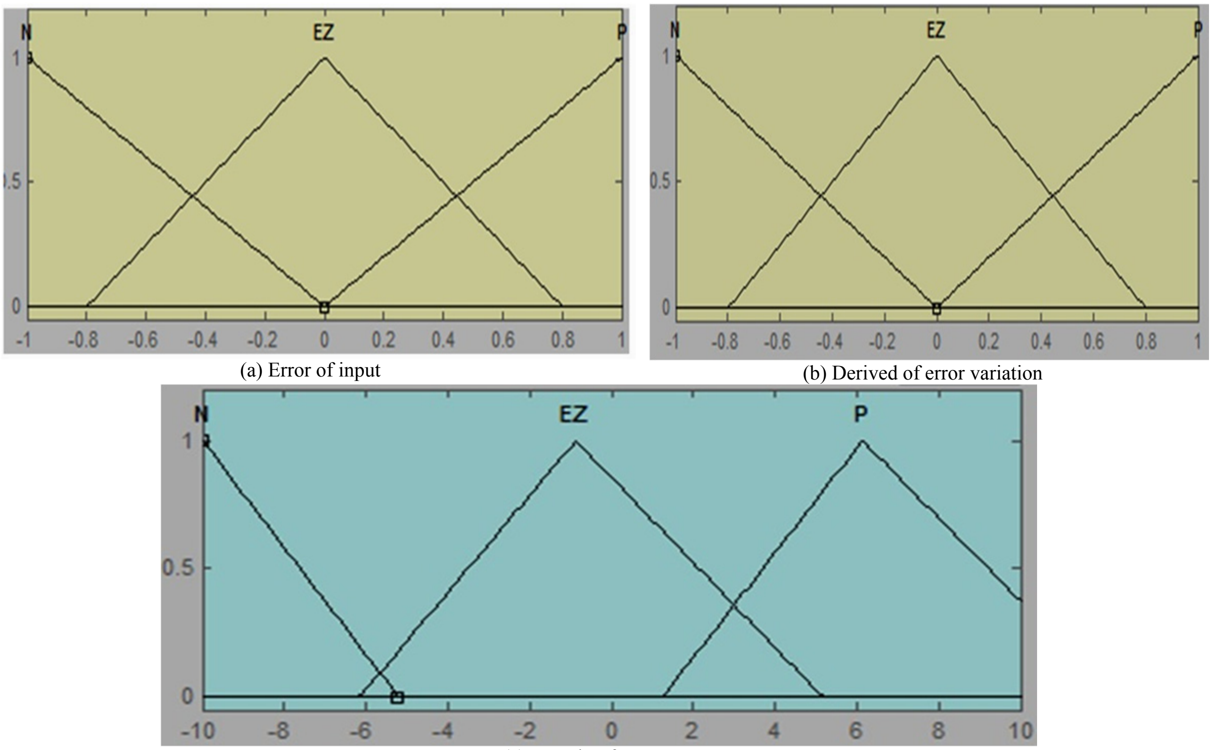
Fig. 4. Membership functions for: (a) Input variable E, (b) Input variable CE, (c) Output variable ΔD

Table 1. Rule base of the fuzzy controller.

E	CE				
	NB	NS	ZO	PS	PB
NB	ZO	ZO	NB	NB	NB
NS	ZO	ZO	NS	NS	NS
ZO	NS	ZO	ZO	ZO	PS
PS	PS	PS	PS	ZO	ZO
PB	PB	PB	PB	ZO	ZO

3.2. Fuzzy logic MPPT controller to wind generator

Our aim is to control the output powers of the machine, in our case the machine is a PMSG based WECS. The developed controller uses the scheme proposed by Mamdani [24]. The major problem encountered during the synthesis of the fuzzy controller is the choice of adaptation parameters that play a most important role in assuring the best performance. So, parameters are varied until a satisfactory response is attended. The selected triangular membership functions are presented under Fig.5. Such, (a) Error for input, (b) Derived of error and (c) Function for output and Table 1 which presents the Decision rules.



(a) Error of input

(b) Derived of error variation

(c) Function for output

Fig. 5. Memberships functions of a fuzzy logic controller

4. Simulation results

4.1. Fuzzy logic results applied for PVG

The simulation results between fuzzy and some of conventional MPPT [11] are shown in Fig.6. It can be seen that the fuzzy MPPT controller reduced the response time. It is also observed that the system with conventional MPPT has a great power loss. A comparison between various MPPT techniques is resumed in Table 3.

Table 2. Decision rules

U		e		
		N	EZ	P
de/dt	N	N	P	P
	EZ	N	P	P
	P	N	P	P

Table 3. Tracking efficiency and response time comparison for different MPPT techniques under stable conditions.

Algorithm	Tracking efficiency, η_{MPPT} (%)	Response time (s)
Fuzzy logic	99.22	0.80
P&O	96.98	2.95

4.2. Fuzzy logic results applied for WG

The proposed control scheme was applied to a typical 3 kW PMSG-based WECS, the parameters of the wind turbine are taken the same as those in [3], for comparison purposes. Fig.7, 8 and 9 show the performance of Fuzzy controller in tip speed ratio (*TSR*), power coefficient and rotor speeds. The mechanical speed of the rotor follows the evolution of wind speed which varies between 16rd/s et 27rd/s corresponds to the variation of wind between 5 m/s and 9.5 m/s respectively. The same for the *Cp* values, it can seen that the proposed fuzzy logic controller ensures maximum power capture and it kept in their optimal values, comparing with referred values [25].

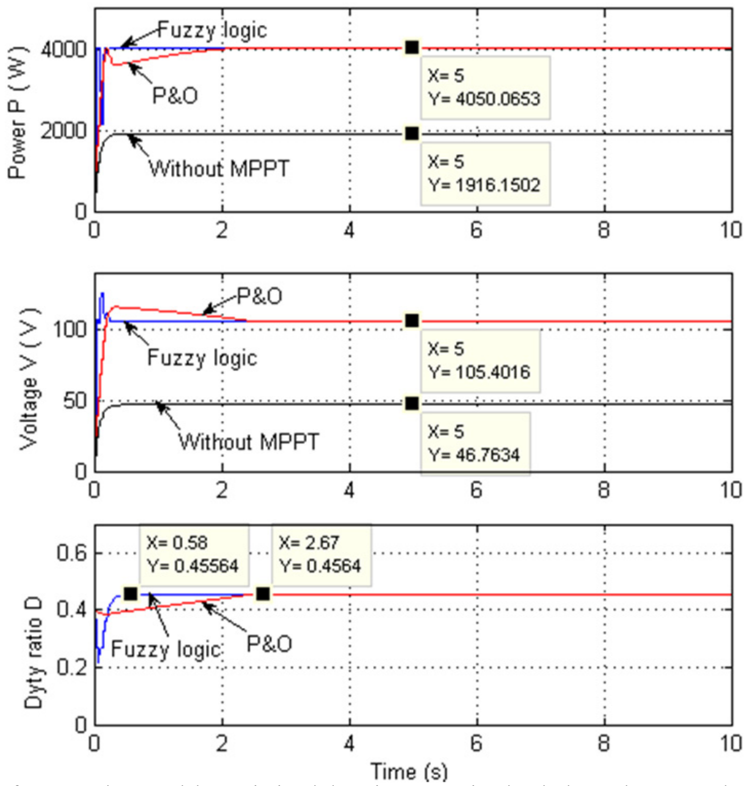


Fig. 6. Comparison of power, voltage, and duty ratiosignals by using conventional and advenced MPPT methods for a 4kW PVG.

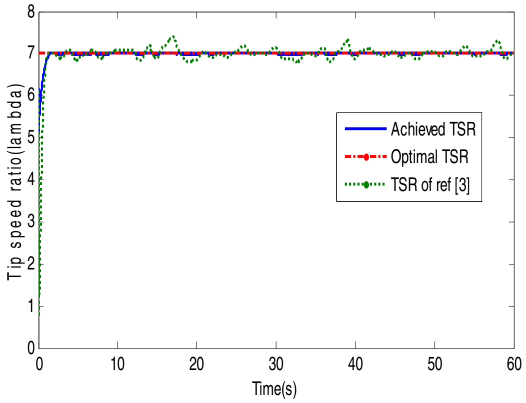


Fig. 7. Achieved tip speed ratio (TSR)

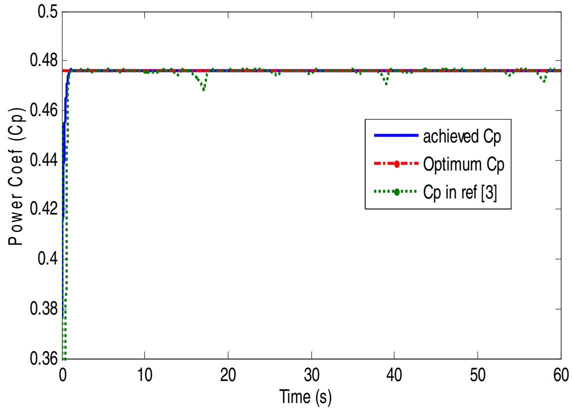


Fig. 8. Achieved power coefficient

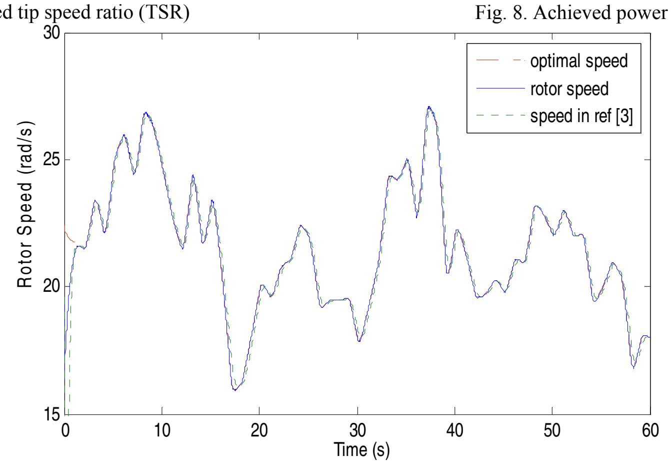


Fig. 9. Optimal and achieved rotor speeds

5. Optimized sizing design

The major concern in the design of the PV-Wind hybrid systems is to determine the size of each component within the system to satisfy a specific load demand. Hence, the optimal system designed is to minimizing the total cost of the system, and ensuring that the load is served according to certain reliability conditions. The total cost is en function of the capital cost of all investigates equipment's, the maintenance and replacement costs [25].

$$Min < Ct >= Min < Ci > + Min < Cm > + Min(Cr) \quad (7)$$
$$Ci = Ppv * Ci_{pv} + Pw * Ci_{w} + Pbat * Ci_{bat} + SinvCi_{inv} \quad (8)$$

The fuzzy logic controller is to assure the MPP of both generators, so the function (15) becomes:

$$Min < Ci >= MPP_{pv} * Ci_{mpp} + MPP_{w} * Ci_{mpp} + min < Pbat >* Ci_{bat} + Sinv * Ci_{\text{inv}} \quad (9)$$

The proposed algorithm is illustrated in Fig. 10.

6. Conclusion

The simulation results for a 7 kW (3kW-WG and 4kW-PVG) are very promising and prove in general that the fuzzy MPPT controller performances, in terms of stability, precision and speed in the tracking of the MPP of both

PVG and WG are much better than those of the conventional method. The implementation of such controllers allows the optimization of the power out of both renewable energy generators (PVG and WG), through a high stability around the MPP against sudden changes of wind speed, solar irradiation and temperature. The stability around the MPP translated directly to optimize sizing rules by minimizing between three (3%) to nine (9%) from the installing powers, which results in economy of energy, and reduces the system total cost.

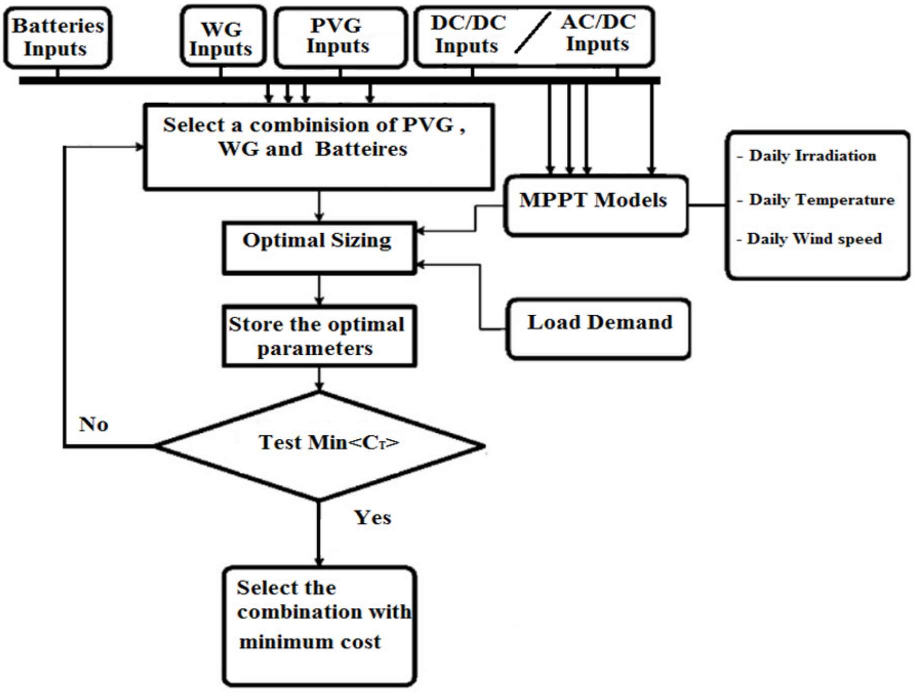


Fig. 10. Flowchart of proposed optimization

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