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A Review on Maximum Power Point Tracking Techniques for Wind and Solar Energy Systems in a Micro-grid

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ABSTRACT

For the optimum operation of a micro-grid, consisting of solar and wind energy generation systems it is required to operate the solar and wind energy systems optimally. Due to instantaneous varying nature of solar irradiance and wind speeds it is required to find optimum operating points of both the systems to ensure maximum energy generation. This paper reviews the various maximum power point tracking techniques of both the solar and wind energy systems.

Keywords: Wind and Solar energy systems, MPPT techniques and algorithms

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I. INTRODUCTION

Wind and solar energy systems have attained high attention in the several past decades as one of the most reliable renewable energy sources. Latest research and development in Renewable energy sources have presented excellent potential, as a form of additional contribution to conventional power generation systems.

Wind turbines are organised to operate only in a pre-defined range of wind speeds bounded by cut-in speed (Vcut-in) and cut-out speed (Vcut-out). Outside these limits, the turbine have to be stopped to defend both the generator and turbine. Fig.1 shows the usual power curve of a wind turbine [1]. It can be detected that there are three dissimilar operational areas. First is low-speed region, in which the turbine must be stopped and disconnected from the grid, to stop it from being driven by the generator [2]. Second area is the moderate-speed area that is restricted by the cut-in speed where the turbine starts working, and the rated speed (Vrated) where the turbine yields its rated power. The turbine yields maximum power in this region.

Variable speed wind turbines are able to modify their rotational speed, to track instantaneous variations in wind speed, they are able to keep a constant rotational speed to wind speed ratio so the maximization of the extracted energy is attainable with variable speed wind turbines only [3]. Since the wind speed is varying instantaneously, it is essential for the rotational speed to be adjustable to maintain the optimum TSR at all times. To work in variable-speed conditions, a wind energy system requires power electronic converters to change the variable-voltage–variable frequency of generator into a fixed-voltage–fixed-frequency which is suitable for the grid [5-7]. There is a specific ratio named the optimum tip speed ratio (TSR) for every wind turbine for which the extracted power is maximized [4].

For grid-connection of the wind turbines, mainly two types of power electronic interfaces are available: back-to-back power converter and diode rectifier +boost circuit + inverter. Back-to back power converter with complex control scheme, allow PMSG based wind turbine to have superior operation performance at high cost. Whereas the second one with diode rectifier and simple control strategy is less costly and more reliable. PMSG based wind turbine with back-to back power converter is broadly investigated in [8-14].

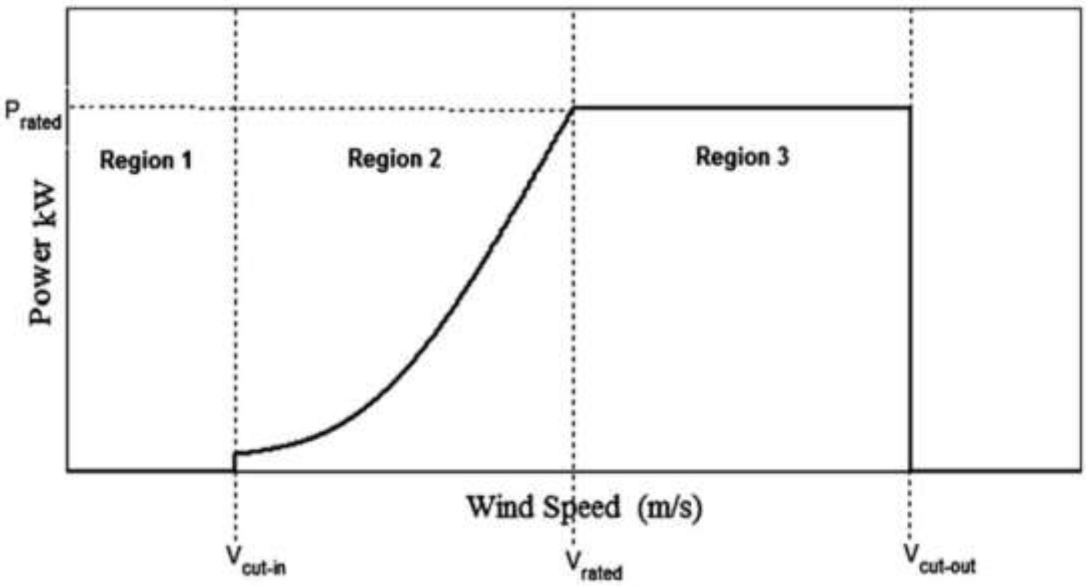

Fig 1. Ideal power curve of a wind turbine.

To maximize the output power of a solar array, it has to be functioned at a sole point with definite voltage and current values, or at a specified load resistance. This needs a separate power converter circuit for the MPPT. Figure2 gives the power–voltage (*P*–*V*) curve of a PV module respectively for different values of solar radiation and temperature [32].

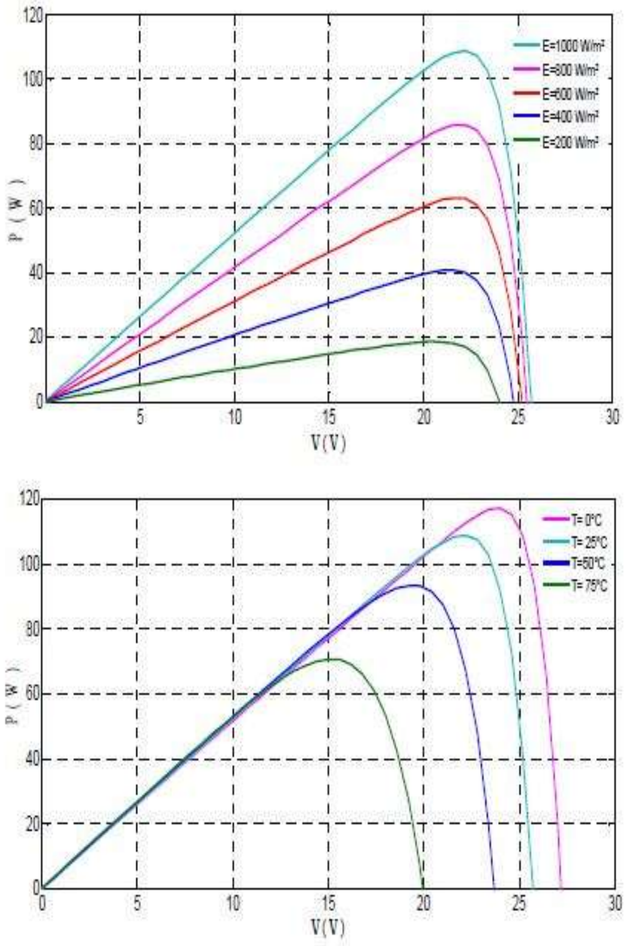

Fig 2. The effect of the irradiation and the temperature on PV generator

The MPPT is a controller which reimburses for the varying Voltage Current characteristic of a solar cell. The MPPT fools the panels into outputting a different voltage and current permitting more power to go into the storage devices by showing the solar cell the load is altering, and actually you are unable to change the load [15]. The MPPT screens the output voltage and current from the solar panel and decides the operating point which will convey that maximum power available to the batteries. If the MPPT can accurately track the always-changing operating point where the power is at its maximum, then efficiency of the solar cell will be increased [32]. Numerous algorithms have been proposed for tracking maximum power point of a PV generator. These algorithms vary in convergence speed, effectiveness, sensors required, complexity, and cost [16].

II. WIND ENERGY SYSTEM

The available wind power from the flowing air is taken by wind turbine and may be expressed as

$$P_{wt} = \frac{1}{2}\rho S V_w^3 C_p(\beta,\lambda) \qquad (1)$$

Where,

P_{wt} = wind power

ρ = air density

S = effective rotor swept area

V_w = wind speed

C_p = power coefficient

β = pitch angle

λ = tip-speed ratio

The value of λ is given by the equation (2). It is function of rotational speed ω, radius of the rotor R and V_w.

$$\lambda = \frac{\omega R}{V_w} \qquad (2)$$

From (1), C_p depends on β and λ representing the aerodynamic characteristic of the turbine. If λ is kept constant, C_p gets larger when β gets less. Similarly, given β constant, there is a value of λ making C_p maximum.

The curve family of C_p versus β and λ is illustrated in figure 3, where $0 = \beta_0 < \beta_1 < \beta_2 < \beta_3 < \beta_4$.

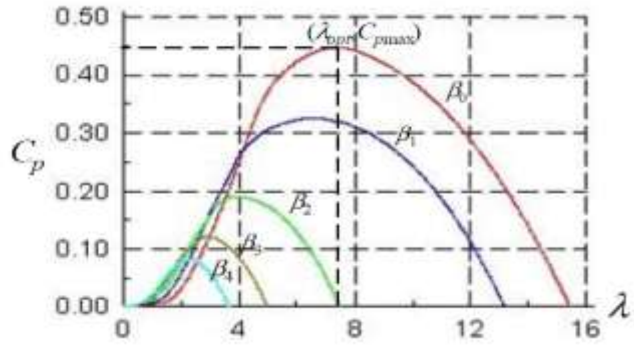

Fig 3. Curve family of C_p versus β and λ

In terms of the wind speed, the action range of the turbine can be separated into MPPT mode and nominal power mode. If wind speed is between cut-in and nominal speeds, the turbine will operate in MPPT mode, demanding the power conversion coefficient to be the maximum $C_{p\max}$. As shown in Fig.3, the pitch angle and the tip-speed ratio should be β_0 and λ_{opt} respectively. The optimal rotor speed at diverse wind speeds can be calculated by (3).

$$\omega_{opt} = \lambda_{opt} V_w \tag{3}$$

When the wind speed go beyond nominal speed, the turbine will function in nominal power mode. In this situations, the pitch angle is controlled to control the wind power captured by the turbine. Fig.4 presents the characteristic of the wind power versus the rotational speed ω of the turbine and the wind speed V_w. Between V_1 and V_5, the turbine operates in MPPT mode between V_6 and V_8, it operates in nominal power mode, where $V_1 < V_2 < V_3 < V_4 < V_5 < V_6 < V_7 < V_8$.

III. SOLAR ENERGY SYSTEM

The photovoltaic system is able to generate DC power without any environmental influence when is exposed to sunlight. The elementary building component of PV arrays are the solar cell, which is fundamentally a p-n junction which directly converts solar irradiance into electricity. The output characteristic of PV module is subjected on the cell temperature, solar irradiation, and output voltage of the module. The figure 5 shows the equivalent circuit of a PV array with a load [17].

Typically the equivalent circuit of a general PV model contains a photocurrent, a diode, a parallel resistor which expresses a leakage current, and a series resistor which describes an internal resistance to the current flow.

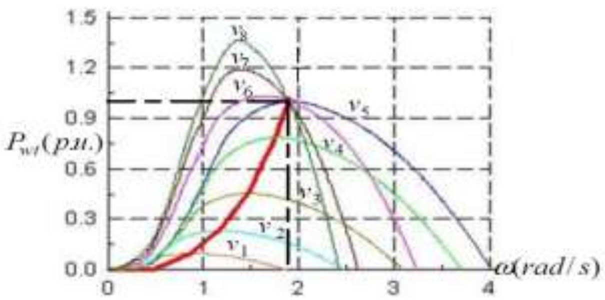

Fig. 4 Characteristic curve of P_{wt} versus ω

The PV array is a collection of several PV modules, and they are electrically connected in series and parallel combination to generate the essential current and voltage. So the current and voltage equation of the array with N_p parallel and N_s series cells can be represented as

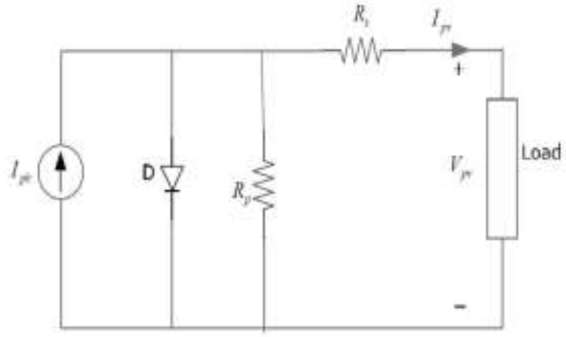

Fig. 5. Equivalent circuit of a solar cell

$$\begin{aligned} I_{pv} &= N_p I_{PH} - N_p I_S[\exp(\mathrm{q}(\mathrm{V_{pv}}/N_s + I_{RS}/N_p)/\mathrm{kT_c}A) - 1] \\ &-(N_p \mathrm{V_{pv}}/N_s + I_{RS})/R_p \end{aligned} \tag{4}$$

The open-circuit voltage $\mathrm{V_{oc}}$ and short-circuit current I_{sc} are the two most significant parameters used to describe the cell electrical performance. The above stated equation is implicit and nonlinear; so, analytical solution for the specific temperature and irradiance is difficult. Normally $I_{PH} >> I_S$, so by ignoring the small diode and ground-leakage currents under zero-terminal voltage, the short-circuit current is nearly equal to the photocurrent, i.e.

$$I_{PH} = I_{sc} \tag{5}$$

The parameter of open-circuit voltage is found by supposing the zero output current. With the given open-circuit voltage at reference temperature and neglecting the shunt-leakage current, the reverse saturation current can be acquired as

$$I_{RS} = I_{sc} / [\exp(\mathrm{qV_{oc}}/N_s kAT_c) - 1] \tag{6}$$

Moreover, the maximum power can be stated as

$$\mathrm{P_{max}} = V_{\max} I_{\max} = \gamma V_{oc} I_{sc} \tag{7}$$

IV. MPPT TECHNIQUES FOR WIND ENERGY SYSTEM

The maximum power extraction algorithms investigated so far can be categorized into following main control methods, namely tip speed ratio (TSR) control, power signal feedback (PSF) control, hill-climb search (HCS) control and Optimal torque (OT) control [18].

A. Tip speed ratio (TSR) control

The TSR control technique adjusts the rotational speed of the generator in order to keep the TSR to an optimal value where the power extracted is maximum. This technique needs both the wind speed and the turbine speed to measure or estimate along with the knowledge of optimum TSR of the turbine in order for the system to become capable to extract maximum possible power. Fig. 6 illustrates the block diagram of a WECS with TSR control.

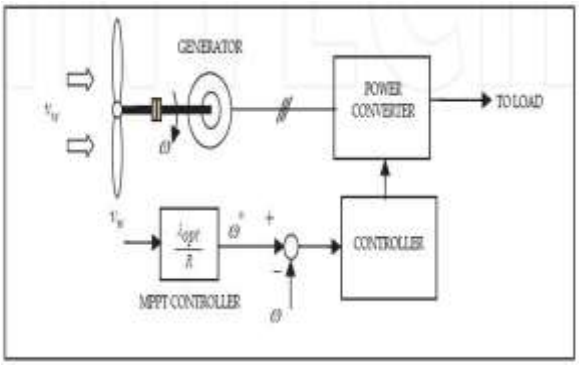

Fig. 6 Tip speed ratio control of WECS [32]

B. power signal feedback (PSF) control

In PSF control, it is essential to know the information of the wind turbine's maximum power curve, and track this curve through its control devices. The maximum power curves are obtained through simulations or off-line experiment on each wind turbines. In this scheme, reference power is produced either taking a recorded maximum power curve or using the mechanical power equation of the wind turbine, where wind speed used as the input. Fig. 7 shows the block diagram of a WECS with PSF controller for maximum power abstraction.

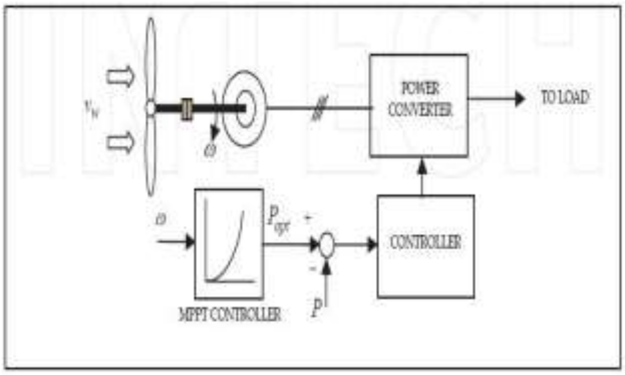

Fig. 7 Power signal feedback control [32]

C. Hill-climb search (HCS) control

The Hill-climb search (HCS) control algorithm continuously examines for the peak power of the wind turbine. It can sort out some of the common problems usually associated with the other two methods. Depending upon the location of the operating point and relation between the variations in power and speed, the tracking algorithm computes the wanted optimum signal in order to drive the system at the point of maximum power. Fig. 8 shows the principle of HCS control and Fig. 9 shows a WECS with HCS controller for tracking maximum power points.

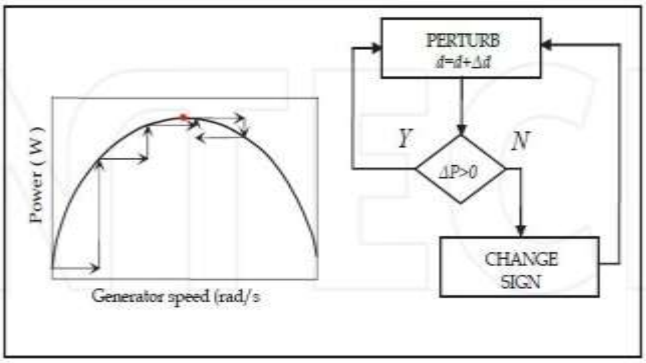

Fig. 8 HCS Control Principle [32]

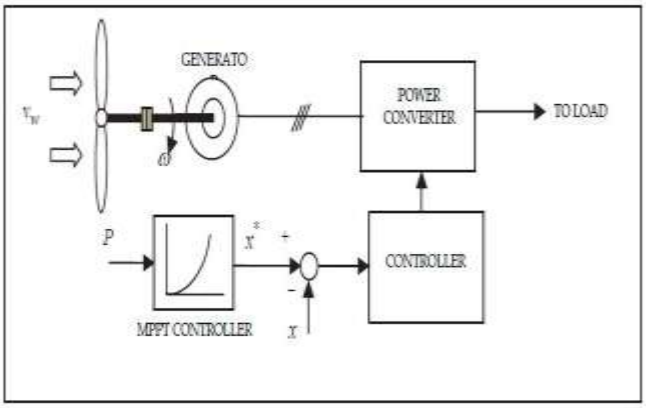

Fig. 9 WECS with hill climb search control [32]

D. Optimal torque (OT) control

As stated previously, keeping the operation of the system at λ_{opt} guarantees the conversion of available wind energy into mechanical form. The block diagram, shown in Fig. 10, shows that the principle of this scheme is to regulate the PMSG torque in accordance with a maximum power reference torque of wind turbine at a specified wind speed. In order to determine the turbine power as a function of λ and ω_m, Eq. (2) is rewritten in the following form to obtain the wind speed [19-21].

$$V_w = \frac{\omega R}{\lambda} \tag{8}$$

By substituting Eq. (8) into Eq. (1), the expression yields:

$$P_{wt} = \frac{1}{2}\rho S \frac{R^3\omega^3}{\lambda^3} C_p \tag{9}$$

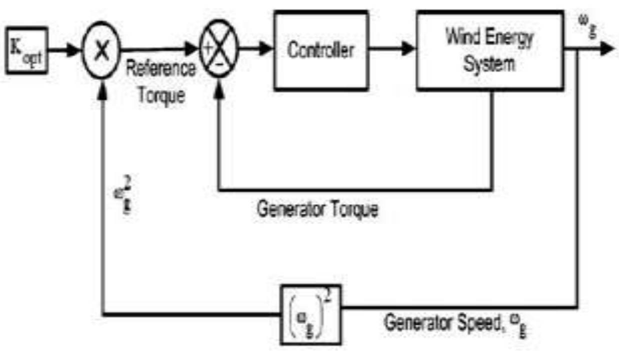

Fig. 10 The block diagram of optimal torque control MPPT method [30]

V. MPPT TECHNIQUES FOR SOLAR ENERGY SYSTEM

A. Fixed Duty Cycle

The fixed duty cycle signifies the simplest of the techniques, and it does not necessitates any feedback, here the load impedance is adjusted only once for the MPP [31].

B. Constant voltage (CV) method

The constant voltage (CV) method utilises empirical results, showing that the voltage at MPP is about 70%–80% of the PV open-circuit voltage , for the normal atmospheric condition. Among the points of MPP (changing atmospheric situations), the terminal voltages of the module varies very slight even when the strength of solar radiation changes, but it alters when the temperature changes. Therefore, this technique must be used in areas where the temperature fluctuates very slight. A positive point is that only the PV voltage is required to be measured, and a simple control loop can reach the MPP [23-24].

C. MPP Locus Characterization

The elementary notion of this method is to find a linear relationship between voltage and current at the MPP (MPP locus). This relationship is a tangent line on the MPP locus curve for the photo current in which the least irradiation condition satisfies the sensitivity of the method. The equation regarding this scheme is given by (10). As one can see, it is difficult to obtain all the necessary parameters, a linear approximation is made offline with the PV panel, translating it as an estimation method. As the MPP locus fluctuates with temperature, the system desires to be updated. This is carried out by measuring the open-circuit voltage periodically, so t the interface converter must open the PV circuit, resulting in loss of energy in these instants. This MPPT technique functions better for high solar irradiations [25].

$$T_l = \left(\frac{\eta.V_T}{I_{MPP}} - N.R_s\right).I_{MPP} + \{V_{oc} - \eta[VD_o + V_T]\} \quad (10)$$

Where N the number of cells, I_{MPP} is the current at MPP, V_T is the temperature voltage, and VD_o is the differential voltage.

D. Perturb and observe method

In this algorithm a small perturbation is given to the system. The power of the module varies due to this perturbation. If the power rises as a result of the perturbation then the perturbation is continued in that direction. When power reaches its crest point, at the next instant power reduces and therefor the perturbation also reverses. During the steady conditions the algorithm oscillates about the peak point. The perturbation size is kept very little to keep the power variation small. It is observed that there is some power loss because of this perturbation and also it fails to track the power under rapid altering atmospheric conditions. But still this algorithm is very popular and simple [26-27].

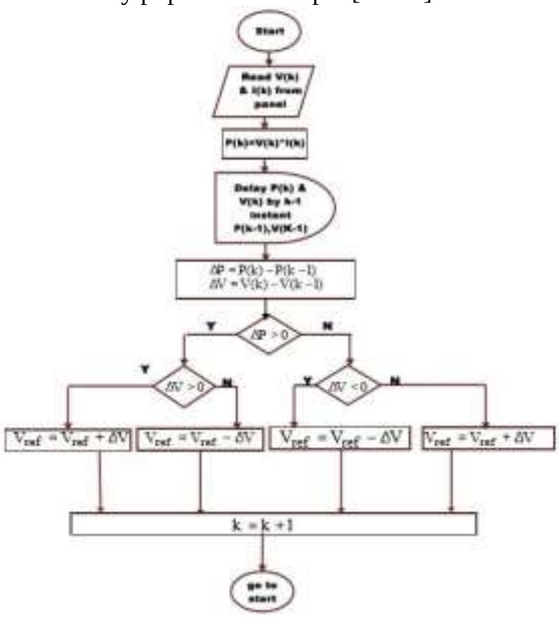

Fig. 11 Flowchart Perturb and observe algorithm

E. Incremental Conductance method

Incremental conductance (IncCond) technique is basically depends on the fact that the slope of PV panel power versus voltage curve is zero at the MPP, positive on the left, and negative on the right of the MPP [28]. The relationship between the instantaneous conductance (I/ V) and the incremental conductance $(\Delta I/\Delta V)$ is given by:

$$\frac{\Delta I}{\Delta V} + \frac{I}{V} = 0 \qquad \text{At MPP}$$

$$\frac{\Delta I}{\Delta V} + \frac{I}{V} > 0 \qquad \text{Left of MPP}$$

$$\frac{\Delta I}{\Delta V} + \frac{I}{V} < 0 \qquad \text{Right of MPP}$$

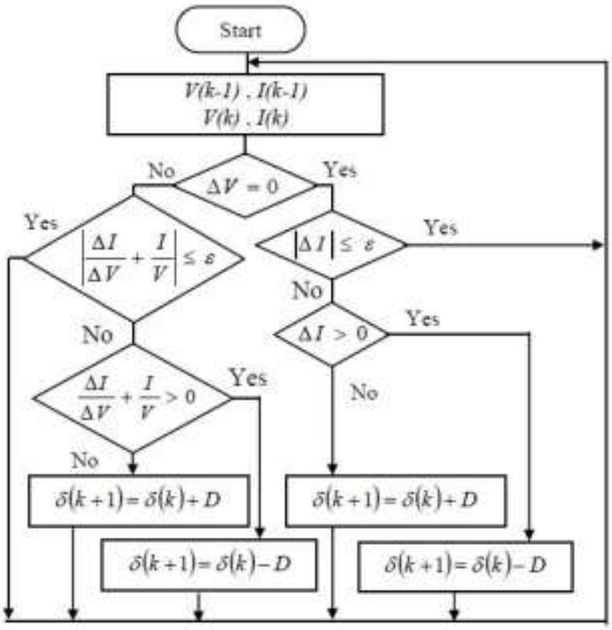

Fig. 12 the InC algorithm flowchart

Because of the noise, of measurement's faults and the quantification, the condition $(\Delta I/\Delta V) + (I/V) = 0$ is rarely satisfied, therefore in steady state, the system oscillate around the MPP. To overcome this drawback we introduce a new parameter ε , as

$$\left|\frac{\Delta I}{\Delta V} + \frac{I}{V}\right| \le \varepsilon \qquad (11)$$

The IncCond algorithm is shown in the flowchart figure 12 [27] The magnitude of the oscillations, around the MPP, is regulated by the values of ε . It reduces with the increase of ε . However, for a comparatively large values of ε, the operating point transfers away from the true MPP. Hence, the parameter ε value is chosen carefully for improved performance of the MPPT system [30].

F. Parasitic capacitances

The enhancement of the incremental conductance pointes to the method of parasitic capacitance, that considers the parasitic capacitances of the solar cells. This method uses of the switching ripple of the MPPT which helps to perturb the array. The average ripple in the PV array voltage and power, produced by the switching frequency are measured by using a series of filters and multipliers and then used to compute the array conductance. Then the algorithm selects the direction of movement of MPPT operating point. One disadvantage is there in this algorithm that the parasitic capacitance in every module is very small, and can perform well in large PV arrays where several PV modules are connected in parallel. There is sizable input capacitor in the DC-DC converter which filters out small ripple in the array power. This capacitor may cover the complete effects of the parasitic capacitance of the PV arrays [27].

VI. REVIEW RESULTS AND DISCUSSION

The main significant features in selecting a particular MPPT strategy for wind energy system are shown in table 1 [4]. The authors studied a simulation and comparison of three selected control methods in terms of efficiency and speed of response. Simulation results confirmed the superiority of the OTC technique in terms of ease and accuracy. This scheme gained the maximum average value of C_p and kept it at its maximum even with variations in wind speed. However, its dependency upon wind turbine characteristics makes it inflexible. On the other hand, the Hill-climb search control technique is flexible and simple in application, but it is fewer efficient and can be problematic in computing the best step-size. In Comparison with perturbation of the duty cycle, perturbation of the input voltage was found suitable in terms of accuracy and response time. Determining the adaptive step-size algorithms and merging two or more of the available techniques will improve the performance and sort out some of the obstacles found in the current methods. Table II précises the main characteristics of the analyzed MPPT algorithms for solar energy systems. Among the techniques examined, the beta method was presented as a good resolution about high-quality TF, diminished and lesser ripple voltage in steady state, better transient performance, and medium complexity of implementation; however, it is dependent on the PV characteristics. It is hard to perform division functions, and in this situation, the digital implementation is required. The idea of applying the MPPT algorithms through digital controllers can be applied to all methods if it were possible to diminish error functions.

VII. CONCLUSION

Wind and Solar energy conversion systems are receiving extensive attention among the numerous renewable energy systems. Withdrawal of maximum possible power from the available Solar and wind power is an important research area among which the wind speed sensor less MPPT control has been a very dynamic region of research. In this literature, a brief review of MPPT control techniques suggested in various literatures for regulating wind and solar energy systems is presented. There is an ongoing work, to make converter and control arrangements more efficient and cost effective in hopes of emerging a financially viable solution to growing environmental issues. Wind and solar power generation has grown up at a shocking rate in the past few decades and it will continue to do so, as power electronic technology continues to advance.

VIII. ACKNOWLEDGEMENT

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TABLE I
Comparison of characteristics of various MPPT methods for WECS [30]

S.N.	Technique	Complexity	Convergence speed	Prior training/ knowledge	Memory requirement	Wind speed measurement	Performance under varying wind conditions
1	Tip speed ratio control	simple	Fast	No	No	Yes	Very god
2	Optimal torque control	Simple	Fast	Yes	No	No	Very good
3	Power signal feedback control	Simple	Fast	Yes	Yes	Yes	Good
4	Hill-climb search control	Simple	Depends	No	No	No	Good

TABLE I
Comparison of major characteristics of MPPT algorithms for solar energy system [31]

S.N.	Method	Dependency on PV Array	Tracking factor	Implementation	Accuracy	Sensors
1	DCTE	No	Poor	Very simple	No	-

2	VCTE	Yes	Reasonable	Simple	No	V
3	P&O	No	Good	Simple	Yes	V,I
4	IC	No	Good	Medium	Yes	V,I

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