Comparision of ‘Perturb & Observe’ and ‘Incremental Conductance’ Maximum Power Point Tracking algorithm on real environmental conditions

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***Abstract*—The trend and need of shifting towards renewable energy sources for electricity generation, has attracted researchers towards photovoltaic (PV) systems for last few decades. Since PV generator has nonlinear behavior, and its output power is a function of solar irradiance and ambient temperature, therefore need of developing maximum power point tracking (MPPT) techniques remains the interest. Among various MPPT techniques, Perturb & Observe (P&O) and Incremental-Conductance (IC) are dominant. This paper describes these two algorithms and compares them in terms of their computational complexity and oscillations near maximum power point (MPP) using MATLAB® & Simulink®. Also testing conditions are based on the real environmental data collected at NED University, Karachi.**

Keywords—Maximum Power Point (MPP), Perturb & Observe (P&O), Increamental Conductance (IC), Duty control

I. Introduction

Increase in energy demand is obvious, with the growth in world’s population. It is expected that world primary energy demand will increase by 60% from 2002 to 2030, globally[1]. Fig.1, shows the energy mix of Pakistan, which reflects a dominant portion contributed by thermal sources and fractional contribution of renewables i.e. wind power [2]. PV is considered one of the most important resources of energy for future[1, 3]. By 2011, almost 30 GW of electricity had been produced by PV solar cell globally [4]. Currently Pakistan lags the capability of harnessing solar energy, though it has a great potential of generating energy through it [4, 5]. In this regard, several projects are initiated that could utilize solar and other renewable energy resources available in Pakistan [5-8].

Efficiency of PV cell plays important role for the feasibility evaluation of power generation with PV. The efficiency of solar panel is low and its capital cost is high when compared with other power generating techniques[9, 10]. Feasibility evaluation is based on a standard testing condition (STC), in which PV cell efficiency is observed by applying 1000 Watt/m^2 irradiance, at 25^{0}C Temperature and air mass of 1.5 [10-12]. [10], summarizes highest confirmed efficiency of commercially employed solar cell, which as listed in Table 1.

Besides lower efficiency, PV solar panel has nonlinear characteristics in terms of current verses voltage (I-V) and power verses voltage (P-V). Also the output power of PV cell is dependent on irradiance and ambient temperature, which are dynamic variables throughout the day timings. In order to extract maximum power from the PV panel, MPPT techniques are applied [12-14].

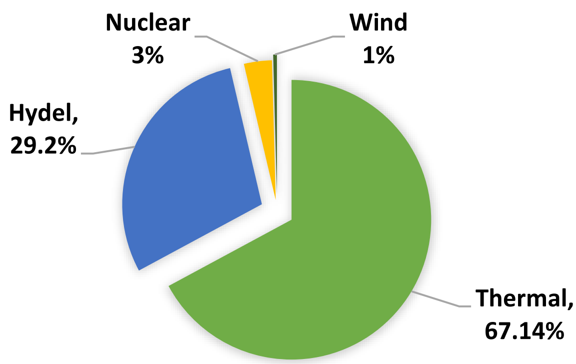

Fig. 1. Energy mix of Pakistan for electricity production [2]

TABLE 1
Solar Cell efficiency measurement under standard testing conditions[10]

Classification	Efficiency (%)	Area (cm^2)	Open Circuit Voltage V_{oc} (V)	Current Density J_{sc} (mA/cm^2)
Si (crystalline)	25.6±0.5	143.7	0.74	41.8
Si (multi crystalline)	20.8±0.6	243.9	0.6626	39.03
Si (thin film mini module)	10.5 ±0.3	94	0.492	29.7

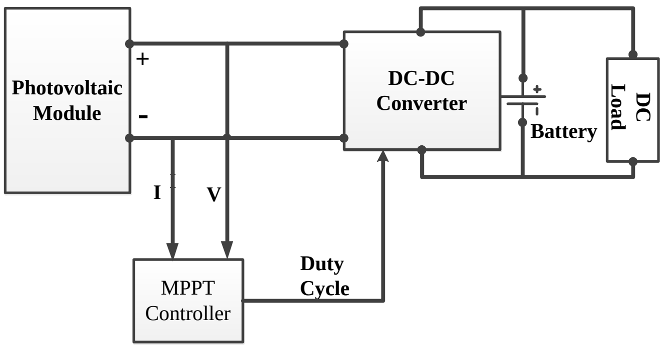

Fig. 2. Typical PV System components[15]

Block diagram of a typical PV system in terms of components is shown in Fig. 2. In principle, the MPPT controller derives the DC-DC converter, which serves as an interface between load and PV cell, by controlling its duty cycle to extract maximum power out of the PV cell based on environmental conditions. The output of DC-DC converter can be used to operate DC load directly and can also be utilized to charge the battery.

In this paper, comparison between P&O and IC is made under real weather condition at NED University Karachi. The work focuses on the implementation of the two techniques in MATLAB® and Simulink®, also describes their ability to handle varying environmental conditions. The organization of the paper is as follow: Section II, describes the modelling of photovoltaic system in Simulink®. In Section III, dynamics of P&O and IC algorithm in terms of MPP tracking are compared and Section IV, has conclusion with results and discussion.

II. PV SYSTEM MODELLING IN SIMULINK

A. PV Solar panel

Literature shows techniques of modeling solar cell in simulations, with a prominent difference of either using single diode solar model or double diode solar model. They exhibit real behavior of device with inclusion of losses [12, 16-20]. In this paper single diode model is used and simulated similarly done in [12]. The equivalent model of single diode solar cell is shown in Fig. 3. The current equation for equivalent solar model is given in "1".

$$I = I_{pv} - I_0 \left[e^{\left(\frac{V+R_S I}{\alpha V_t}\right)} - 1 \right] - \frac{V+R_S I}{R_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here I_{pv} = photovoltaic current (Ampere)

I_0 = Saturation current (Ampere)

Thermal voltage $= V_t = \frac{N_s kT}{q}$ (Volts)

N_s = number of cells connected in series

k = Boltzmann constant (Joule/Kelvin)

T= Temperature of solar cell (Kelvin)

q = The elementary charge on an electron. (Coulomb)

R_s = equivalent series resistance of the PV array (Ohms)

R_p = equivalent parallel resistance of the PV array (Ohms)

N_P = Number of cells connected in parallel

Based on single diode model the solar array having model number as KC200GT has been simulated in this paper[12]. The parameters of the solar array been given in Table 2 under STC. Characteristics of modeled solar cell can be measured in terms of power verses voltage (P-V) curves and is given in Fig. 4.

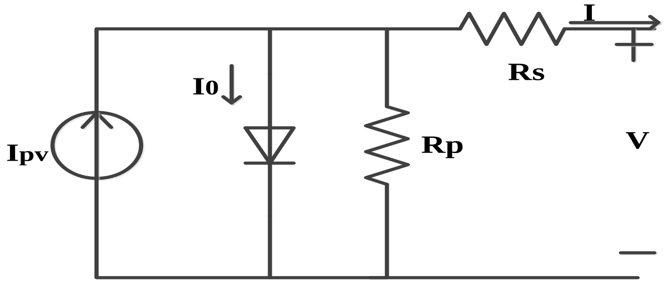

Fig. 3. Equivalent Model of Single Diode Solar cell[12]

TABLE II
Parameters of solar array KC200GT at STC

Maximum Power	P_{max} (W)	$200 \pm 10\%/-5\%$
Current at MPP	I_{mpp} (Ampere)	7.61
Voltage at MPP	V_{mpp} (Volts)	26.3
Short circuit current	I_{scc} (Ampere)	8.21
Open circuit voltage	V_{oc} (Volts)	32.9
Number of cell in series	N_s	54

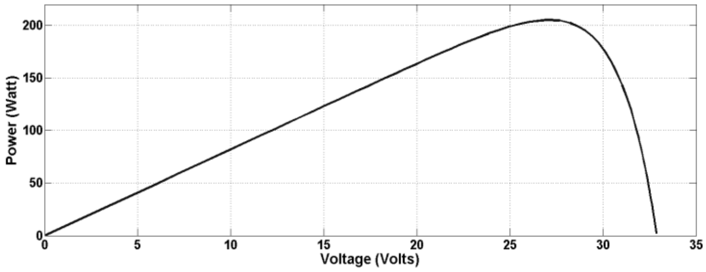

Fig. 4. PV Curve of modeled solar panel @ STC constant condition

Fig.5, shows power dependency of solar panel on irradiation condition. The PV curve at various irradiance i.e. at 1000 W/m^2, 800 W/m^2, 600 W/m^{2,} 400 W/m^2 and 200 W/m^2 are shown in Fig. 5. While the temparature of panel kept constant at 25^{0}C. Clealry the MPP varies in proportion with irradiance.

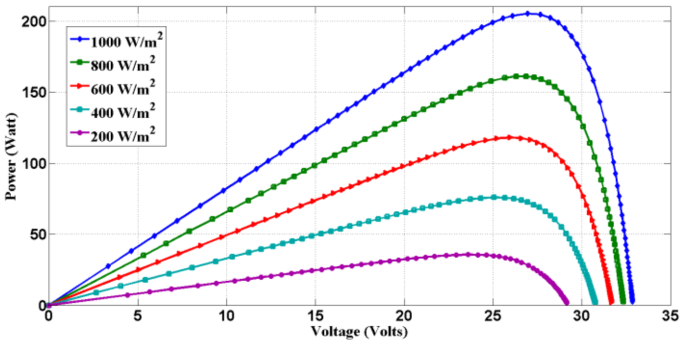

Fig. 5. PV Curve at different irradiance

B. MPPT Algorithm

The Purpose of MPPT algorithm in PV system is to keep the PV panel voltage closes to MPP voltage. Several authors has contributed towards novel MPPT techniques and compared these techniques [21-26]. Many Authors have compared two fundamental MPPT techniques i.e. P&O and IC in literature [27, 28]. With the best of knowledge, no author has done the qualitative comparison showing MPPT algorithm performance in MPP tracking. Furthermore duty control dynamics also not shown in MPP tracking. The qualitative comparison of both algorithm is explained here with the real weather conditions at NED University, Karachi.

1) Perturb & Observe MPPT Algorithm

In this method the solar panel voltage is first perturb and output power is calculated. If the power increases on increasing voltage, then voltage is further increased. If the power decreases on increase in voltage then the voltage of panel is reduced to search for higher value of output power. The variations in operating voltage is controlled by a constant value. Since the algorithm always keeps searching for MPP, the P&O algorithm keeps the panel output power oscillating around MPP. This method is simple because, it uses calculation of maximum 3 steps to track MPP. The oscillation of output power in P&O is natural and also the weakness of algorithm. In literature modified versions of P&O are given that improve MPP tracking performance but no proof is presented for better performance in variable irradiation condition [29-31]. The flow chart in Fig. 6, summarizes the P&O algorithm.

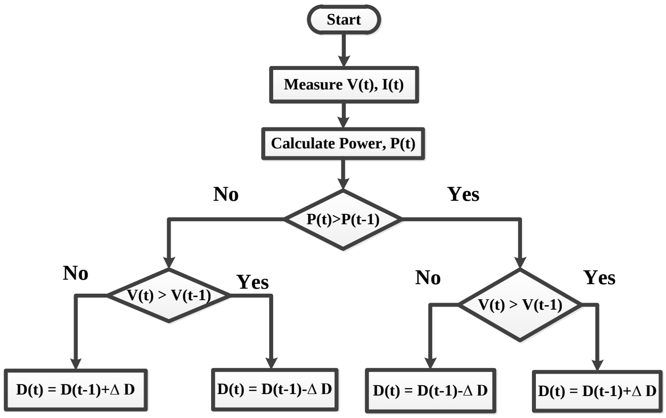

Fig. 6. P&O MPPT algorithm[28]

2) Incremental Conductance MPPT Algorithm

This method addresses the deficiency in P&O algorithm under variable irradiance conditions. In order to reach at MPP this method uses the slop of differential voltage dV and current dI. The relationship of IC algorithm is shown in "(2)", "(3)" and "(4)" [32].

$$\frac{dI}{dV} = -\frac{I}{V} \qquad (\frac{dP}{dV} = 0). \quad \text{At MPP} \ldots\ldots\ldots\ldots\ldots (2)$$
$$\frac{dI}{dV} > -\frac{I}{V} \qquad (\frac{dP}{dV} > 0). \quad \text{At the left of MP} \ldots\ldots (3)$$
$$\frac{dI}{dV} < -\frac{I}{V} \qquad (\frac{dP}{dV} < 0) \quad \text{At the right of MPP..} (4)$$

The perturbation in the voltage is applied until "(2)" is achieved. And the direction of perturbation can be determined by equation "(3)" and "(4)". The flow chart of IC algorithm is shown in Fig.7.

The disadvantage of P&O algorithm under rapidly changing irradiance condition is overcome by using IC algorithm [33]. P&O oscillate at MPP, while IC can find its MPP and perturbation is clogged. There is a disadvantage of IC as compared to P&O is its complexity level. The maximum 7 step calculation takes place in IC [34, 35].

C. DC-DC Converter

In this work, the buck converter is employed because it has been proved in literature, that the buck converter has better efficiency at all light level among other types of DC-DC converters [36, 37]. The Inductor of 50 mH and capacitor of 1mF have been used. The equivalent circuit is shown in Fig. 8.

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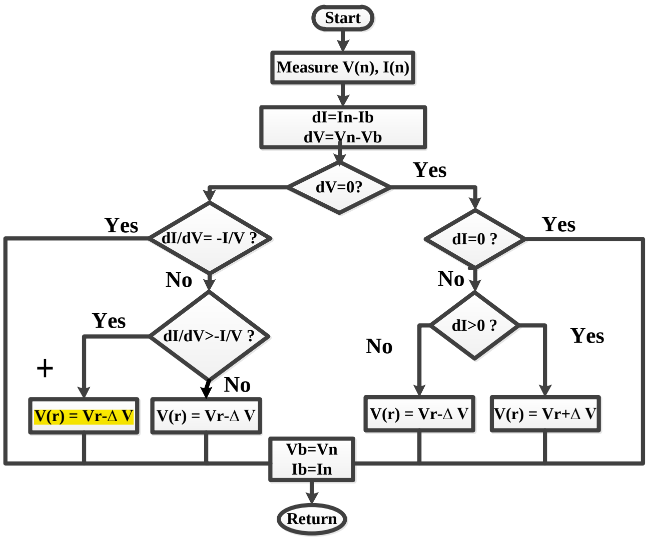

Fig. 7. IC MPPT Algorithm[28]

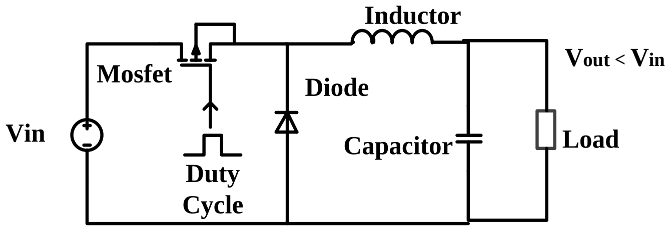

Fig. 8. Equivalent Buck Converter circuit [38]

III. SIMULATION RESULTS ON MPPT COMPARISION

1) At STC

To show dynamics of PV system using P&O and IC at STC, a simulation for 0.5 sec was performed and results of MPP achieved with duty control at MPP tracking are shown in Fig. 9 and 10 respectively. These results assume that irradiation of constant value 1000 Watt/m^2 was kept at temperature 25^{0}C. At this condition system move from zero-initial condition to the steady-state value.

2) At real environmental conditions at NED University

Since system simulation had to consider the dynamics of irradiance and temperature for the complete day, instead of running simulation for 3600 seconds on Matlab®. Because of memory constraints, the parameter dynamics are scaled for 67 seconds only. After monitoring weather conditions for a month started from 23rd Dec 2015 to 23rd Jan 2016, it is concluded that weather pattern looks same throughout the month. Therefore a typical day profile can be chosen to test the simulation. The real solar irradiance and ambient temperature of a typical day 23rd Dec 2015 has been selected. The solar irradiance and ambient temperature for a day is shown in Figs. 11 and 12 respectively. Considering real atmospheric conditions shown, simulation of PV system using P&O and IC MPPT algorithm has been run. The results been shown in Figs. 13 and 14 respectively.

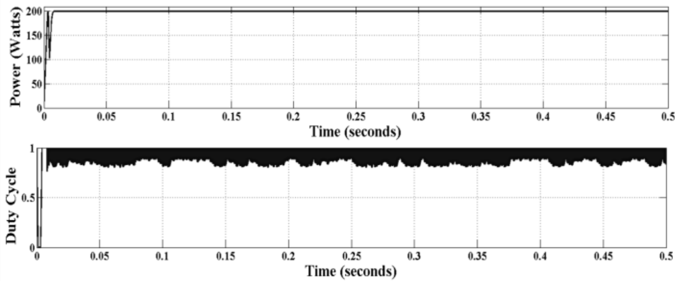

Fig. 9. PV panel Power and Duty cycle control using P&O at STC

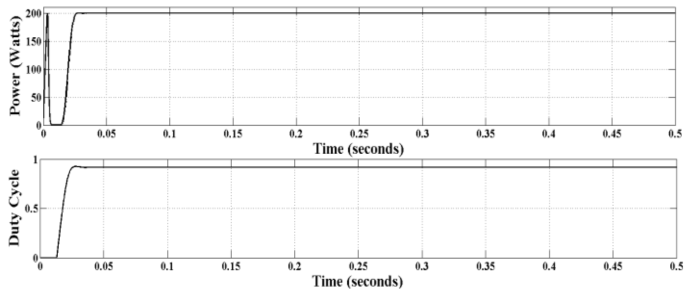

Fig. 10. PV panel Power and Duty cycle control using IC at STC

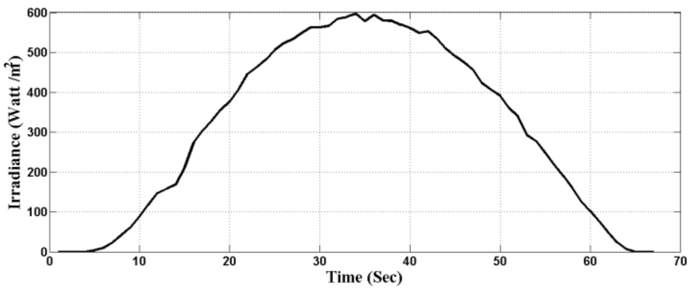

Fig. 11. A typical day solar irradiance pattern at NED University

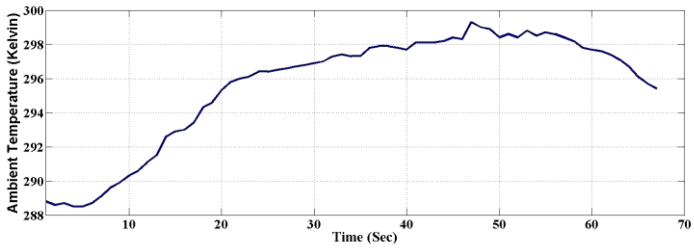

Fig. 12. A typical day ambient Temperature pattern at NED University

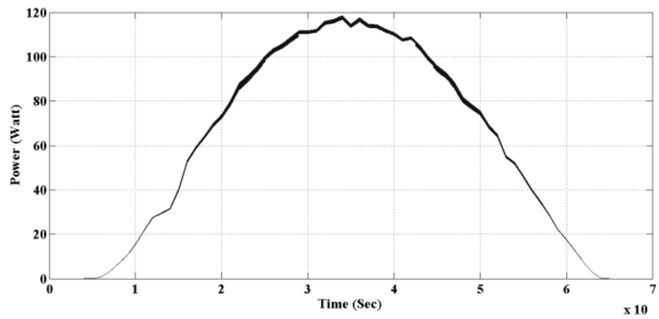

Fig. 13. P&O simulation results on a typical day profile

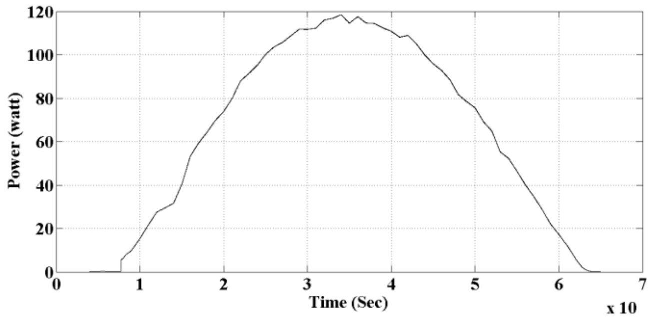

Fig. 14. IC simulation results on a typical day profile

IV. Results and Discussion

1) Comparison at constant irradiance Condition

The PV system performance by using P&O and IC MPPT algorithm at STC are shown in Figs. 9 and 10 respectively. Fig. 9, clearly depicts that at constant irradiation, P&O finds MPP quickly but oscillate at MPP. While as shown in Fig. 10, IC finds MPP after time delay. But the oscillations at constant irradiation are less as compared to P&O.

The major finding in this work is the representation of duty control dynamics of both algorithm. As shown in Fig. 9, duty cycle of P&O is perturb continuously and results in greater oscillation at MPP. While in Fig. 10, duty cycle of IC is not changed continuously, it provides fine control on duty cycle. This fine control on duty cycle provide less oscillation at MPP and better tracking performance at variable irradiance conditions. If same fine control is gained by P&O then its duty control dynamics will be improved and will results in lower oscillations and better tracking MPP performance.

2) At real environmental conditions at NED University,

Simulation results are then compared at real weather data obtained at NED University weather station. A typical day irradiance and temperature profile is shown in Figs. 11 and 12. When the simulation under same condition run on both MPPT algorithm. The results are shown in Figs. 13 and 14. As Fig. 13, shows the P&O follows the irradiation pattern, but with increased number of oscillation while tracking MPP. This shows incompetency of P&O to find MPP at variable irradiance condition or practical scenario. Fig. 14, shows how efficiently IC follows irradiance pattern. As the power output has low oscillations and better MPP tracking performance in real weather conditions.

Conclusion

It is found that P&O MPPT algorithm has better tracking performance at constant environmental conditions i.e. constant irradiance and temperature which is not a good representation of real weather conditions. But even at constant condition i.e. at STC, duty control dynamics of P&O is poor as compare to IC. IC has better MPP tracking performance as compare to P&O in variable environmental conditions such as clouds moving over panel which results in variation of irradiance. Under real weather conditions at NED University, performance of IC MPPT algorithm was found to be better as compare to P&O.

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