Stand-Alone PV System Using Adaptive Control

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***Abstract*—There are many applications today in which photovoltaic (PV) modules can be used, in particular small off-grid loads (stand-alone), such as basic lighting, refrigeration, telecommunications and water pumping. In some of these cases, a Direct Current (DC) motor is connected to a PV module (PVM) as load; hence, these PV systems must be studied to improve their efficiency and to increase their growth. The matching could be reached in two ways:-First, without interfacing circuit, selecting carefully the load according to a load I-V curve, mechanical load characteristics and PV parameters. Second, by including an electronic control device like (adaptive control), known as maximum equilibrium point tracker (MPPT), which continuously matches the output characteristics of the PV to the input characteristics of the load. This paper only addresses the second way, which uses an interfacing circuit in order to match photovoltaic modules to a load. The adaptive controller is a control system that frequently adjusts the electrical operation point of the PV modules to the maximum equilibrium point, the mechanism of the adaptive controller by adjusting the duty ratio of (DC-DC) power converter, which used as interfacing circuit between PV and load.**

***Index Terms*—stand-alone PV system, adaptive control and simulations.**

I. Introduction

In a modern control system, electronic intelligence controls some physical process. Control systems are the "automatic" in such things as automatic pilot and automatic washer. Because the machine itself is making the routine decisions, the human operator is freed to do other things.In many cases, machine intelligence is better than direct human control because it can react faster or slower (keep track of long-term slow changes), respond more precisely, and maintain an accurate log of the system's performance [1]. A regulator system automatically maintains a parameter at or near a specified value. An example of this is a home heating system maintaining a set temperature despite changing outside conditions. A follow-up system causes an output to follow a set path that has been specified in advance. An example is an industrial robot moving parts from place to place. An event control system controls a sequential series of events. An example is a washing machine cycling through a series of programmed steps.Natural control systems have existed since the beginning of life. Consider how the human body regulates temperature. If the body needs to heat itself, food calories are converted to produce heat; on the other hand, evaporation causes cooling. Because evaporation is less effective (especially in humid climates), it is not surprising that our body temperature (98.6°F) was set near the high end of Earth's temperature spectrum (to reduce demand on the cooling system)[2]. If temperature sensors in the body notice a drop in temperature, they signal the body to burn more fuel. If the sensors indicate too high a temperature, they signal the body to sweat.Every control system has (at least) a controller and an actuator (also called a final control element). The controller is the intelligence of the system and is usually electronics.

II. Implementation

MATLAB simulations was used to implement the PV stand –alone system. First, they are verified to locate the MEP correctly under the constant irradiance and temperature (25°C) as shown in Fig. 1, the traces of PV operating point are shown in green, and the MPP is the red asterisk.

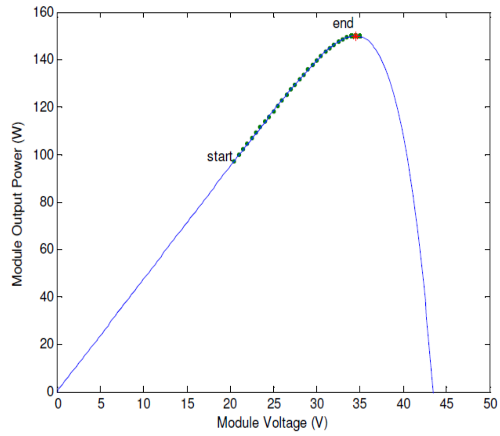

Figure 1. Searching the MEP (1KW/m2, 25°C)

The irradiance data for a specific location over a daytime it's necessary to make comparisons between of

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two adaptive methods, each simulation contains only the PV model and the method in order to isolate any influence from a converter or load. The actual irradiance data provided by the centre of solar energy studies (CSES) in Tripoli (Mrada / Bir-aljafer), for PV stand-alone system used for water pumping, and it's measured every ten minutes for sunny day, cloudy day and half cloudy in different month during 2010.

Irradiance values between two data points are estimated by the cubic interpolation in MATLAB functions.

III. First Simulation with Sunny Day

Simulation with sunny day of 1 May 2010, the measured data for 13 hours and 10 minute divided to 47400 samples. Fig. 2 shows the irradiance from 05:20am to 06:30 pm [3].

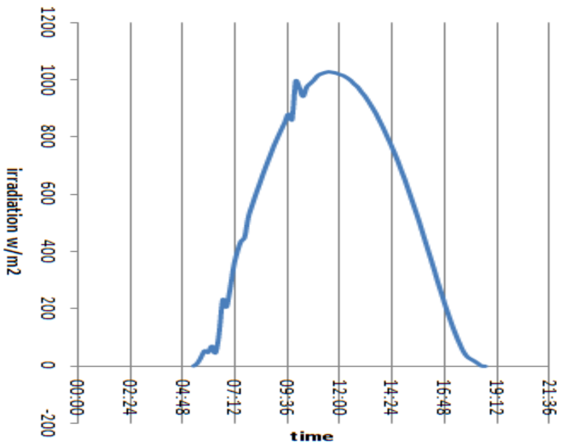

Figure 2. Irradiance data for sunny day of 1 May 2010.

A- Perturb and Observe Method

Fig. 3 shows the trace of PV operating points for P&O method during a sunny day at temperature (25°C).The algorithm locates and maintains the PV operating point (equilibrium point) very close to the MEPs (shown in red asterisks) [4].

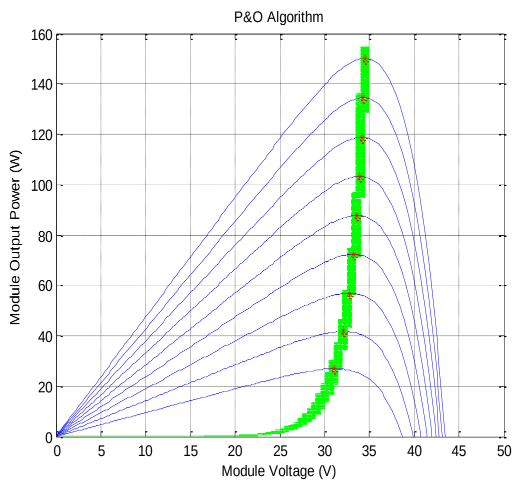

Figure 3. Traces of MEP on a sunny day (25°C)

The Fig. 4 shows the oscillations of the output voltage aroundthe MPP in the steady state, due to the fact that thecontrol is discrete and the voltage and current are not constantly at the MPP butoscillating around it. The size of the oscillations depends on the size of the rate ofchange of the reference voltage.

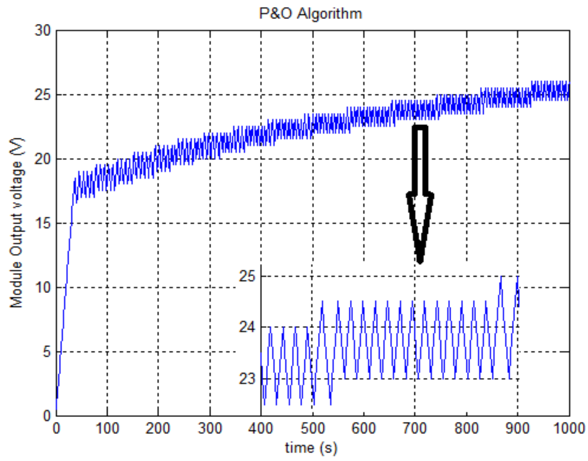

Figure 4. Output voltage oscillate around the V_m

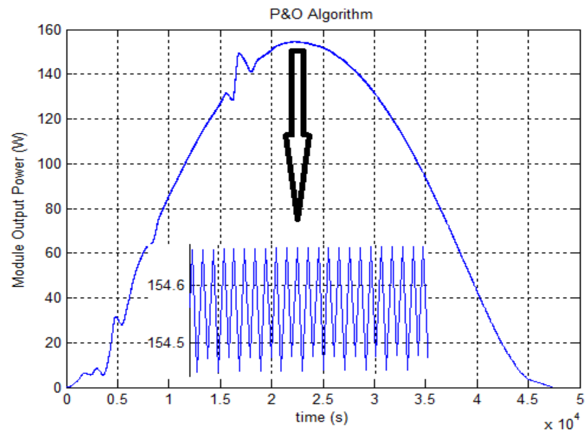

Figure 5. Output power oscillate around the MPP

When the size of the rate of change of the V_{ref} increased, the oscillations around the MPP are greater but the time to reach the steady state is shorter than in the other case, when the size of the rate of change of the V_{ref} decreased. The voltage is reaches to (24 v) at (570 s). The output power of PV module during a sunny day at temperature (25°C) is shown Fig. 5. When the irradiation is constant, operating point (equilibrium point) oscillates around the MPP value. The amplitude of the oscillations depends directly on the size of the increment in the reference voltage.How fast the steady state is reached, and the amplitude of the oscillations is a trade off, as both cannot be improved at the same time, if one is reduced the other increases, because both depend directly on the size of the voltage increment.

B- inCcond Method

The Fig. 6 shows the trace of PV operating points for incCond method during a sunny day at temperature (25°C). The algorithm locates and maintains the PV operating point (equilibrium point) very close to the MEPs (shown in red asterisks) [5].

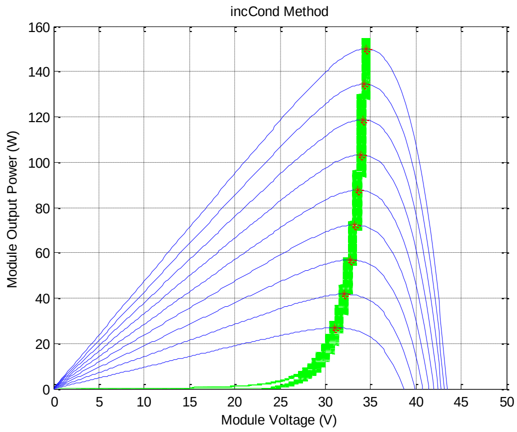

Figure 6. Traces of MEP on a sunny day (25^{o}C)

The oscillations of the output voltage around the MEP in the steady state are shown in Fig. 7. The incCond algorithm is supposed to outperform the P&O algorithm under rapidly changing atmospheric conditions. A close inspection of Fig. 7 shows that the voltage with incCond algorithm is smoother and reaches to (24 v) at (90 s).

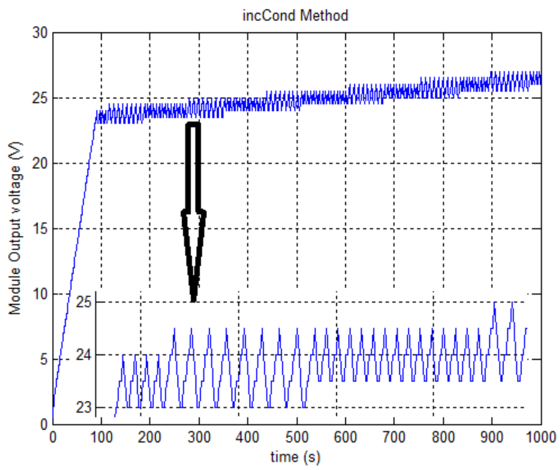

Figure 7. Output voltage oscillate around the V_m

The Fig. 8 shows the output power of PV module during a sunny day at temperature (25^{o}C). The results of the incCond algorithm are practically identical to P&O algorithm in a sunny day.

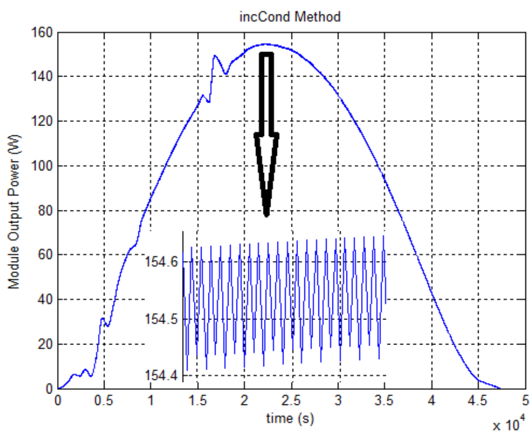

Figure 8. Output power oscillate around the MPP

The different occur between the PV with the MEPT and without MEPT as shown in Table I.

TABLE I. COMPARISON OF P&O WITH INC-COND ALGORITHMS ON CLOUDY DAY

	Sunny day		Cloudy day	
	P&O	incCond	P&O	incCond
Total Energy (simulation) (Pact)	525.8900	525.8900	202.5189	202.5189
Total Energy (theoretical max) (Pth)	526.2784	526.2784	202.6830	202.6830
Efficiency	99.92	99.92	99.92	99.92

Total electric energy produced with the two methods is similar. The MEP tracking efficiency measured by {Total Energy (simulation)} ÷ {Total Energy (theoretical max)} ×100%. Further optimization of algorithm and varying a testing method may provide different results. The simulation results showed the efficiency of 99.92% for the P&O algorithm and 99.92% for the incCond algorithm for the three simulations.There is difference between system with MEPT and without MEPT in energy produced.The only factor to choose one of them is the simplicity. It can be seen, comparing the flowchart of both [6].

IV. CONCLUSION

The result shows that the PV model using the equivalent circuit in moderate complexity provides good matching with the real PV module. Simulations perform comparative tests for the two adaptive methods using actual irradiance data. The incCond algorithm is supposed to outperform the P&O algorithm under rapidly changing atmospheric conditions, they have similar results. Even a small improvement of efficiency could bring large savings if the system is large enough. However, it could be difficult to justify the use of incCond method for small low-cost systems since it requires four sensors. In order to develop a simple low-cost system, this paper adopts the direct control method which employs the P&O method but requires only two sensors for output.This control method offers another benefit of allowing steady-state analysis of the DC-DC converter, as opposed to the more complex state-space averaging method, because it performs sampling of voltage and current at the periodic steady state. The simulation performs of the whole system and verifies functionality and benefits of MEPT. Simulations also make comparisons with the system without MEPT in terms of total energy produced. The results validate that MEPT can significantly increase the efficiency of energy production from PV and the performance of the PV system compared to the system without MEPT.

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