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Real Time Implementation of Variable Step Size Based P&O MPPT for PV Systems Based on dSPACE

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ABSTRACT

Nowadays Solar energy is an important energy source due to the energy crisis and environment pollution. Maximum power point tracking (MPPT) algorithm improves the utilization efficiency of a photovoltaic systems. In this paper an improved P&O MPPT algorithm is developed and simulated using MATLAB/SIMULINK to control the DC/DC buck converter. The obtained simulink model is also verified using dspace tool. Both the simulated and experimental results are validated by also comparing them with conventional MPPT methods. The performance measures show the increase in the efficiency of PV system by the proposed model.

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NOMENCLATURE

I_{PH}	light generated current
I_S	cell's saturation of dark current
I_{RS}	cell's reverse saturation current
q	electron charge
k	Boltzmann's constant
A	ideal factor
T_C	cell's working temperature
T_{Ref}	cell's reference temperature
E_G	band-gap energy
λ	solar insolation in kW/m^2
I_{SC}	cell's short-circuit current at a 25°C and $1kW/m^2$
K_I	cell's short-circuit current temperature coefficient
V_{OC}	open circuit voltage
R_{sh}	shunt resistance
R_s	series resistance
N_s	Number of series cells
N_p	Number of parallel cell

1. INTRODUCTION

Renewable energy sources like photovoltaic and wind generators are widely used. Photovoltaic systems produce DC electricity. Photovoltaic generation is becoming increasingly important in a renewable source since it offers many advantages such as no fuel cost, not being polluting and emitting no noise. Photovoltaic's sources are used today in many applications such as battery charging, home power supply, water pumping and satellite power systems etc. The internal characteristics of PV cell are highly non-linear because of the fast varying sunshine and atmospheric conditions. Therefore to achieve maximum possible power from PV source irrespective of the temperature and insolation off line and on-line MPPT techniques can be used. PV modules still have relative low conversion efficiency as it is sensitive to weather conditions like solar irradiation and temperature [14]. An off line voltage and current based techniques is not suitable for fast varying atmospheric condition [3]. In the online P&O and INC algorithm based on the fixed step size the disadvantages is the power drawn from pv array with a larger step size contributes to faster dynamic but excessive steady state oscillations whenever a smaller step size is required and steady state output cannot be reached. [9]. The advantages of (P&O) method are easy to implement, control scheme is simple, and the cost is less compare to other techniques [7]. To extract the maximum possible power from the PV module a modified P&O algorithm have been developed which breaks the limitations in the sensitivity of the tracker consisting of a buck-type DC-DC converter and can be controlled by a dSPACE unit. The modified P&O algorithm adjust the step size of the voltage to achieve maximum power point is carried out using MATLAB/SIMULINK and dSPACE environment. This method periodically perturbs the array terminal voltage/current and compares the PV output power with that of the previous perturbed power. To increase the PV power the MPPT moves the operating point in such a way to change the PV array voltage otherwise viceversa.

2. MATHEMATICAL MODEL OF A PV MODULE

Electrical model of PV module is developed based on the shockly diode equation. Solar cells consist of a P-N junction fabricated in a thin wafer. In the dark the I-V characteristics is similar to the diode and when exposed to light photons with energy more than the band gap energy of the semiconductor are absorbed and create an electron-hole pair. Under the influence of internal fields of the P-N junction the carriers are swept apart and creates a current proportional to radiation. When open circuited this current is shunted internally by the intrinsic P-N junction diode. Thus the simplest equivalent circuit of a PV cell is a current source in parallel with a diode as shown in Figure 1. Output of the current source is directly proportional to the light falling on the cell. The characteristics equation for this PV array is given by [11]

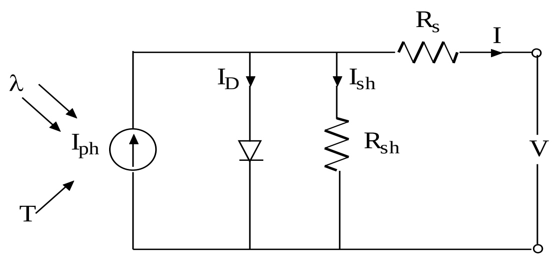

Figure 1. Equivalent circuit of a solar cell

Apply Kirchhoff's current law

$$I = I_{PH} - I_D - I_{SH} \tag{1}$$

$$I_D = I_S \left[\exp\left(q \left(\frac{V + IR_s}{k * A * T_C} \right) \right) - 1 \right] \tag{2}$$

$$I_{SH} = \frac{V + IR_s}{R_{sh}} \tag{3}$$

Substitute equation (2) and (3) in (1) we get

$$I = I_{PH} - I_S \left[\mathrm{Exp}\left(\frac{q * (V + IR_s)}{k * A * T_C} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \tag{4}$$

$$I_{PH} = [I_{SC} + K_I(T_C - T_{Ref})]\,\lambda/1000 \quad (5)$$

$$K_I = \frac{I_{SC(T_2)} - I_{SC(T_1)}}{T_2 - T_1} \quad (6)$$

$$I_S = I_{RS}\left(\frac{T_C}{T_{Ref}}\right)^3 \left[\exp[\left(\frac{q*E_G}{KA}\right)\left(\frac{1}{T_{Ref}} - \frac{1}{T_C}\right)]\right] \quad (7)$$

$$I_{RS} = \frac{I_{SC}}{\left[\exp\left(\frac{q*V_{oc}}{N_S KA\,T_C}\right) - 1\right]} \quad (8)$$

$$I = N_p * I_{PH} - N_p * I_S\left[\mathrm{Exp}\left(\frac{q*(V+IR_S)}{N_s*K*A*T_C}\right) - 1\right] - \frac{V+IR_S}{R_{Sh}} \quad (9)$$

Since a typical PV cell produces less than 2.5W at 0.58V approximately, the cells must be connected in series configuration on a module to produce enough high power is represented in equation 9 where I and V are cell's output current and voltage. The Rs and R_{sh} are calculated [10] by iteration method. Equations 5 to 9 are modeled using Matlab/SIMULINK. All the model parameters are identified from the manufacturer's data specification of a KCP 12060 solar modules are under standard test conditions (STCs) of solar irradiation 1000W/m^2 and temperature is 25°C as in Table 1. The simulated the I-V and P-V curves of a solar module under standard test conditions are shown in Figure 2.

Table 1. Data specification of KCP 12060 module

Data specification	Rating
Open circuit voltage V_{OC}	21.20 V
Short circuit current I_{SC}	4.03 A
Voltage at maximum power V_{mp}	17 V
Current at maximum power I_{mp}	3.50 A
Rated power	59.5 W
Number of cell's in series N_s	36
Number of cell's in parallel N_p	1

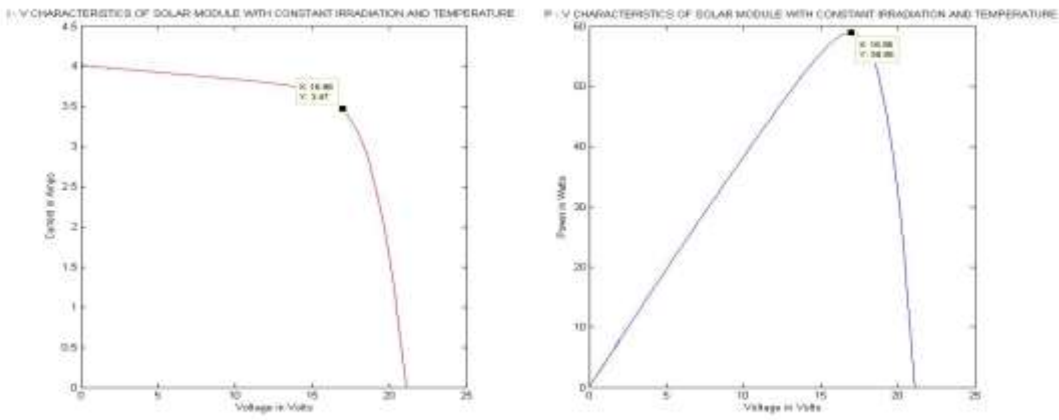

Figure 2. I-V and P-V curves of solar module under standard test conditions

3. BUCK CONVERTER

DC-DC converters are used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by a PWM at a fixed frequency and the switching device used is a MOSFET. DC-DC converter is a high speed on/off semiconductor switch. It connects source to load and disconnects the load from source at a fast speed. A step-down converter produces an average output voltage, which is lower than the DC input voltage V_{in}. The basic circuit of a step-down converter is shown in Figure 3. In continuous-conduction mode of operation, assuming an MOSFET switch, when the switch is on for the time duration t_{on} the inductor current passes through the switch, and the diode becomes reverse biased. This results in a positive voltage across the inductor, which, in turn, causes a linear increase in the inductor current i_l. When the switch is turned off, because of the inductive energy storage, i_l continues to flow. This current flows through the diode and decreases. Average output voltage can be calculated in terms of the switch duty ratio as

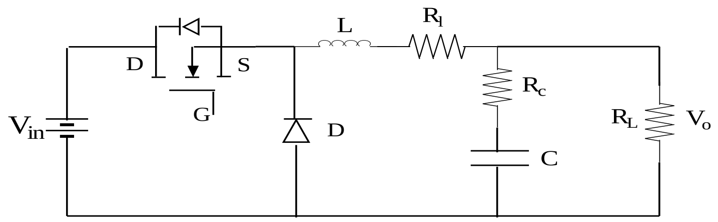

Figure 3. Buck converter

$$V_o = \frac{T_{on}}{T} V_{in} \tag{10}$$

$$D = \frac{T_{on}}{T} \tag{11}$$

To design the buck converters parameters based on [13] the buck converter parameters values as shown in Table 2. The state space model of the buck converter can be derived and then to determine of the controller that will meet the transient and steady state specifications of the closed loop system. The process of adjusting the controller parameters [12] in order to meet given performance specifications is known as controller tuning. The most common Ziegler Nichols tuning method is used for tuning PI controller based on step response to find the Kp and Ti values.

Table 2. Data specification of Buck converter

fs	Vin	V_o	L	C	R_L
20Khz	21V	12V	15mH	10µF	30 & 50Ω

4. MAXIMUM POWER POINT TRACKING

When a solar module is used in a system, its operating point is decided by the load to which is connected. The efficiency of PV system can be improved if the PV module is operated at maximum power point irrespective of varying atmospheric conditions. The MPPT mechanism is based on the principle of impedance matching between load and PV module, which is necessary for maximum power transfer. The impedance matching is done by using a DC to DC converter. The impedance is matched by changing the duty cycle of the switch. There are many MPPT techniques available [5]. Among which the perturb and observe and incremental conductance algorithm are the online MPPT techniques. It is suitable for fast varying irradiation and temperature. The perturb and observe are simple and easy to implement compared with incremental conductance algorithm. Fuzzy logic and neural network are artificial intelligent methods it is experts based systems. The perturb and observe can be divided into two methods voltage reference and direct duty ratio method [6]. In this paper the block diagram of proposed variable step size P & O direct duty ratio method is shown in Figure 4. The principle of the P&O algorithm is to increase or decrease the voltage by adjusting the duty cycle. In the flow chart if dp/dv >0 the duty cycle is decreased and if dp/dv <0 then the duty cycle is reversed shown in Figure 5. Thus increase and decrease of the duty cycle is based on the step size ΔD. If the perturbation fixed step size ΔD chosen is small the system convergence speed towards the MPP is slow and hence desired level of duty cycle is not achieved. If the ΔD is made high the system oscillates around the MPP. To overcome this problem and also to increase the efficiency a PI control loop is developed to adjust the perturbation step size. This proposed variable perturbation step P&O algorithm is suggested in this paper. The proposed method achieves reduced oscillation around the MPP and stable operation of the PV panel.

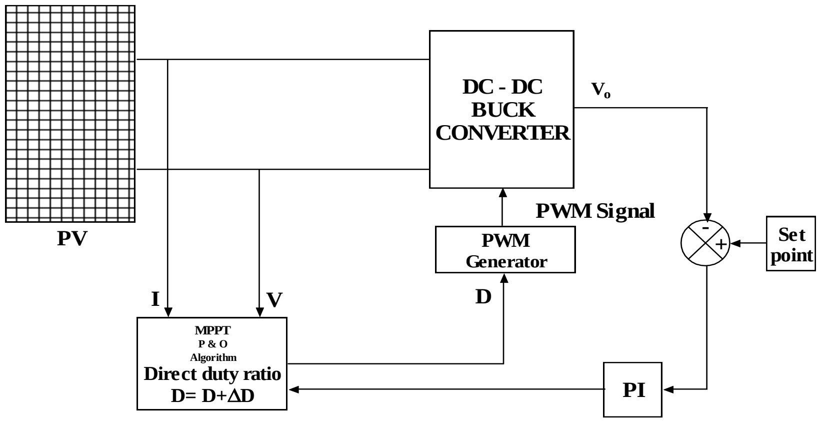

Figure 4. Block diagram of variable step size perturb and observe

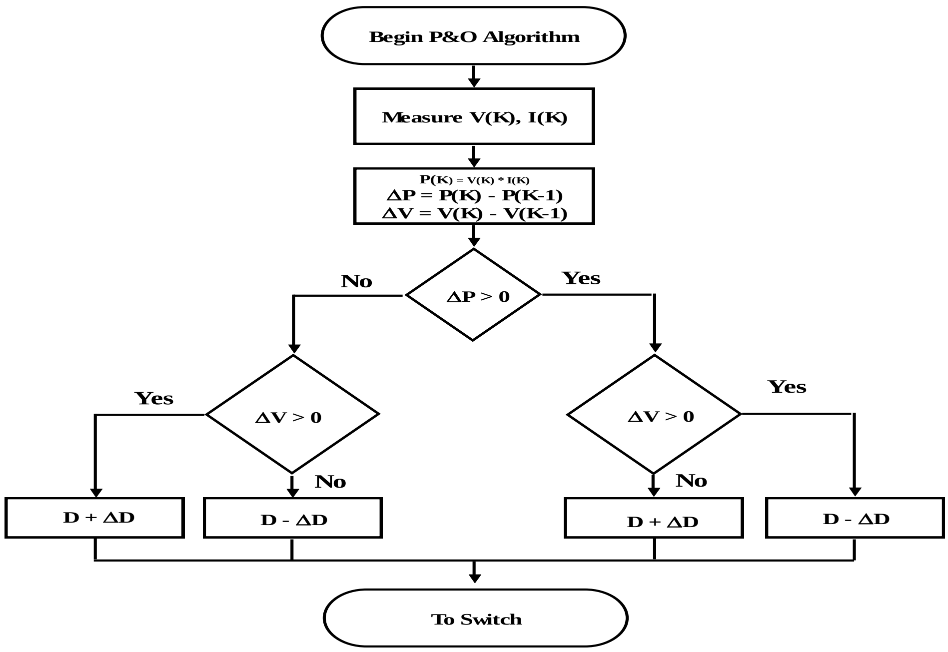

Figure 5. Flow chart of P&O method

5. dSPACE BASED IMPLEMENTATION OF MPPT

The dSPACE DS1102 was first used at Bradley University in the year 2000 when a users manual and a workstation based on this board were developed. Since then, a newer dSpace DS1103 board has become available. The proposed variable perturbation step P&O controller is designed and simulated using the SIMULINK and the dSPACE blocksets, the Matlab-to-DSP interface libraries, Real-Time Interface to SIMULINK, and Real-Time Workshop on a PC. Inputs to and outputs from the DS1103 pass through the CLP1103 connector panel for the DS1103 board. The control system has been developed using MATLAB/Simulink and then automatically processed and run in the DS1103 PPC card.A Graphical User Interface (GUI) has been built using the software control desk of dSPACE. It allows the real-time evaluation of the control system. “control desk” serves multiple uses. It provides the interface for downloading controller models designed in SIMULINK onto the DSP. The instrument panel feature of control desk is used to display various measurements such as the duty cycle of the PWM signal, voltage, current, error and the controller output signals must be sent through the “CLP1103” and “DS1103” before the measurements can be displayed in control desk on the computer.The “CLP1103” serves as an interface between the “DS1103” and the external hardware portion of the overall system. The CLP1103 contains connectors for 20 Analog-to-

Digital inputs, 8 Digital-to-Analog outputs, several other connectors that can be used for Digital I/O, slave/DSP I/O, incremental encoder interfaces, CAN interface and serial interfaces. Output from the DS1103 includes the PWM signal for the gate of MOSFET of buck DC-DC converter.

6. SIMULATION AND EXPERIMENTAL RESULTS

Simulations are carried out using Matlab Simulink. Figure 6 shows the variations in temperature and irradiation and is used as input. Figure 7 shows the input & output voltage, current and power for fixed step size perturb and observe algorithm. When T_C=25°C and λ = 250 W/m^2 and R_L=60Ω, T_C=28°C and λ=400 W/m^2 and R_L=30Ω and T_C=30°C, 33°C, 35°C and λ = 600W/m^2, 800W/m^2 and 1000W/m^2 and R_L=5Ω for the input and output voltage, current and power is shown in Table 3 for different step size ΔD. If ΔD is small it cannot reach the power whenever ΔD is high it oscillates at verh high so this the disadvantages of fixed step size so we can proposed method for variable step size perturb and observe algorithm for different irradiations and temperatures.

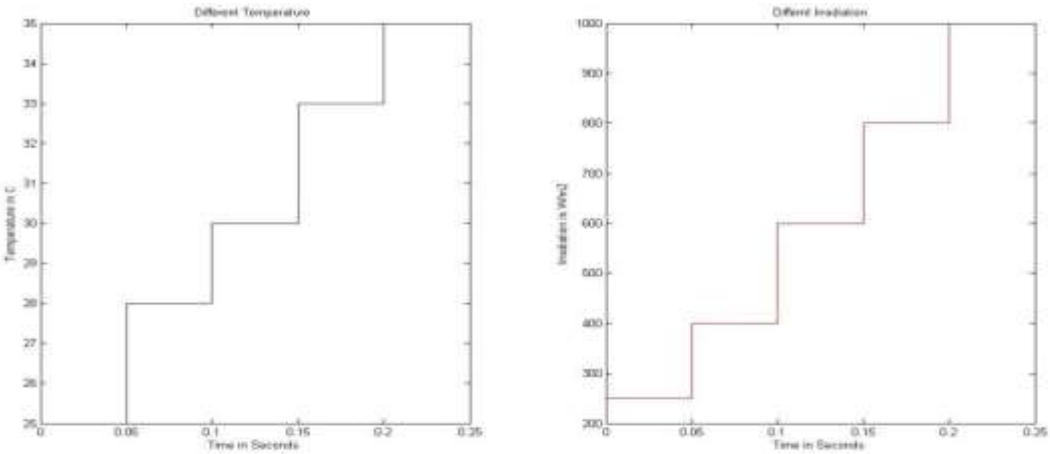

Figure 6. Different Temperatures and Irradiations

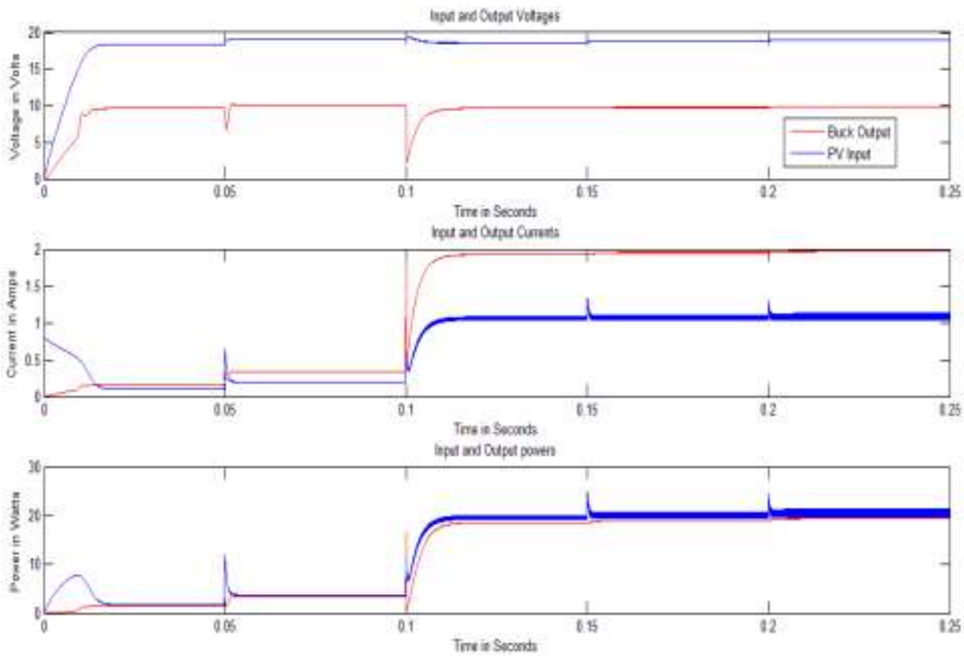

Figure 7. Simulated Input & Output Voltage, Current and Power waveform of a fixed step size based P&O

Table 3. Simulated Input & Output Voltage, Current and Power values of a fixed step size based P&O

Parameters	Different temperature and irradiation					
	R_L=60Ω		R_L=30Ω		R_L=5Ω	
	ΔD=0.015	ΔD=0.045	ΔD=0.015	ΔD=0.045	ΔD=0.015	ΔD=0.045
PV Voltage (V)	18.35	18.3	19.12	19.07	18.98	18.82
PV current (A)	0.09796	0.1116	0.193	0.2279	1.047	1.252
PV Power (W)	1.796	2.043	3.691	4.348	20.98	24.2
Buck Vout (V)	9.632	10.45	10.04	10.91	9.847	10.65
Buck Iout (A)	0.1607	0.1744	0.3346	0.3638	1.969	2.128
Buck Pout (W)	1.548	1.824	3.357	3.969	19.19	22.26
Percentage of Power (%)	86.1	89.2	90	91	91.5	91.8

Table 4. Simulated Input & Output Voltage, Current and Power values of a variable step size based P&O

Parameters	PV Voltage Volts	PV Current Amps	PV Power Watts	Buck Vout (V)	Buck Iout (A)	Buck Pout (W)	Percentageof Power (%)
	Different temperature and irradiation						
R_L=60Ω	18.2	0.1427	2.596	12	0.2002	2.402	92.5
R_L=30Ω	19	0.2665	5.068	12	0.4	4.797	94.6
R_L=5Ω	17.09	1.755	29.99	12	2.401	28.82	96

Figure 8 shows the input & output voltage, current and power for variable step size perturb and observe algorithm. When T_C=25°C and λ = 250 W/m^2 and R_L=60Ω, T_C=28°C and λ=400 W/m^2 and R_L=30Ω and T_C=30°C, 33°C, 35°C and λ = 600W/m^2, 800W/m^2 and 1000W/m^2 and R_L=5Ω for the input and output voltage, current and power is shown in Table4 for variable step size P&O for give better results in voltage, current and power compared with fixed step size P&O algorithm. The fixed and variable step sizes based perturb and observe algorithm is implemented in hardware using Dspace setup is shown in Figure 9.

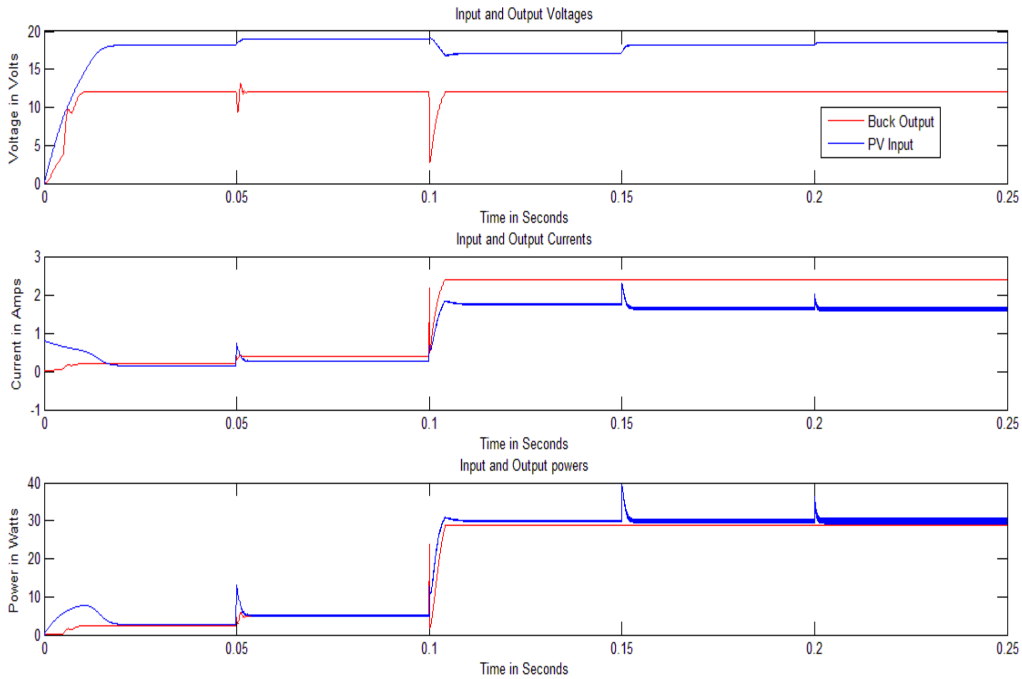

Figure 8. Simulated Input & Output Voltage, Current and Power waveform of a variable step size based P&O

The input and output voltage, current, power and cro output of PWM and output voltage of the Fixed and variable step size based perturb and observe is shown in Figure 10, 11, 12 & 13. The Fixed step size perturb and observe of different step size ΔD value and variable step size based perturb and observe and different load resistance of the input and output voltage, current and power is shown in Table 5.

Figure 9. Hardware setup of PV fed Dspace based DC-DC converter

Figure 10. PWM and output voltage waveform of a fixed step size based P&O using DSO

Figure 11. Real time Input & Output Voltage, Current and Power display of a fixed step size based P&O in dSPACE control desk

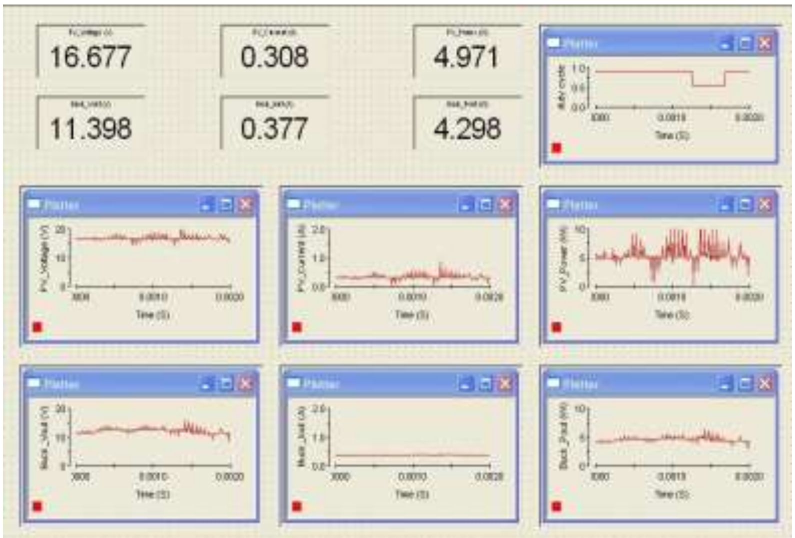

Figure 12. Real time Input & Output Voltage, Current and Power display of a variable step size based P&O in dSPACE control desk

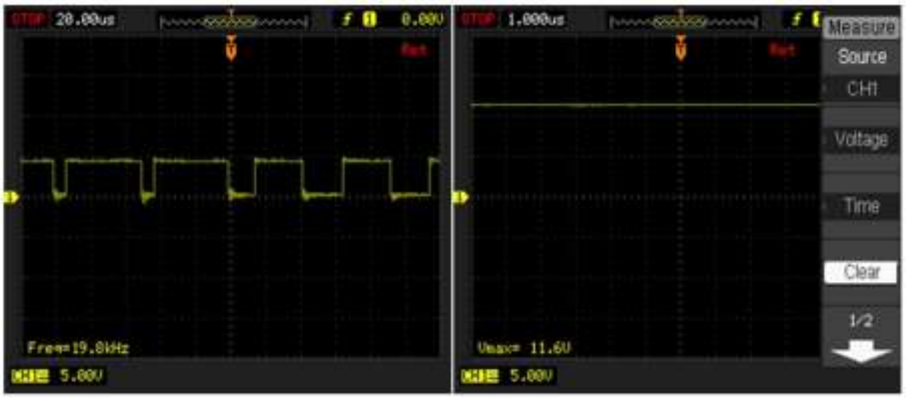

Figure 13. PWM and output voltage waveform of a variable step size based P&O using DSO

Table 5. Real time Input & Output Voltage, Current and Power comparative values for fixed and variable step size based P&O

Parameters	Po Fixed step size and R_L = 30 Ω			Po Fixed step size and R_L = 60 Ω			PO Variable step size	
	ΔD = 0.015	ΔD = 0.030	ΔD = 0.045	ΔD = 0.015	ΔD = 0.030	ΔD = 0.045	R_L = 30 Ω	R_L = 60 Ω
PV Voltage (V)	17.014	16.888	16.607	17.955	17.548	17.449	16.677	17.842
PV Current (A)	0.153	0.151	0.134	0.096	0.084	0.085	0.308	0.137
PV Power (W)	2.596	2.551	2.230	1.726	1.473	1.491	4.971	2.535
Buck Vout (V)	8.006	7.951	7.955	8.216	8.381	8.566	11.398	11.810
Buck Iout (A)	0.234	0.247	0.223	0.138	0.139	0.140	0.377	0.184
Buck Pout (W)	1.874	1.966	1.770	1.134	1.153	1.202	4.298	2.176
Percentage of power (%)	72.18	77.06	79.37	65.7	78.27	80.61	86.46	85.83

7. CONCLUSION

This paper presents the satisfactory performances of the proposed variable step size based perturb and observe algorithm for the photovoltaic system. Generally the fixed step sizes perturb and observe MPPT algorithm is widely used. The selection of step size by the trial and error method for the conventional P&O MPPT algorithm is cumbersome.The changes in step size gives great impact on the increases or decreases of the output power, is a disadvantage. This disadvantage is eliminated by the proposed variable step size method as the step size is automatically changed by means of a feed back controller. The proposed method also regulates the output voltage irrespective of the dynamic disturbances temperature and irradiation. The output power efficiency is improved by 5% to 7% in simulation and is also validated by the hardware result obtained using Dspace DS1103 RTI as shown in Table 5 for the load resistor R_L value 30Ω and 60Ω. The simulation and the hardware results debicts the superiority of the proposed method over the conventional method.

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