# A New MPPT Method for Photovoltaic Generation Systems Based on Hill Climbing Algorithm

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***Abstract*-This paper presents a new method for MPPT in Photovoltaic systems based on "Hill Climbing" algorithm. According to the proposed method cube of slope of Power vs. Voltage (P – V) curve is calculated in each calculation step. Through this calculation both the direction of Photovoltaic's (PV) voltage change and the step size of this change are resulted without making any slope or sign control. Moreover, a way to apply this method in PV systems which are consisted of Ns in series and Np in parallel connection PV arrays with high installed nominal power is proposed. A DC to DC buck – boost converter is used in connection with PV arrays for achieving operation in Maximum Power Point and keeping output voltage constant. The whole system is simulated using Matlab/Simulink and simulation results are presented and analyzed.**

## I. Introduction

In recent years, due to big demand of electrical energy, extended research in electricity production from solar energy using Photovoltaics has been done. Basic advantage of these energy sources is the abundance of solar radiation in nature and environmental friendly way of electricity production. Although the high cost of PV panels and their still low efficiency, high power PV farms have been constructed lately around the world. A lot of research has been done in the field of maximizing output power of PVs when these are coupled with a wide range of loads, batteries or grid, by using Power Electronics converters. These converters may be DC/DC or DC/AC single and three phase converters [1], [2], [3], [4], [5]. Either they may be multilevel inverters. Control strategy for these converters is based on many algorithms which have been developed and improved for Maximum Power Point (MPP) detection, such as Incremental Conductance, Perturbation and Observation (P&O), Hill Climbing, Parasitic Capacitance and Constant Voltage and Current algorithm. Although its complexity, most usual MPPT algorithm is Incremental Conductance due to several advantages that presents in comparison with others [6], [7]. Current research in the field of Maximum Power Point Trackers focuses on new and more flexible ways for duty ratio step size changing. In this paper, a new approach of Hill Climbing algorithm which makes use of a variable step of desirable voltage change is presented. This algorithm is applied on a DC/DC buck – boost converter. According to this new control scheme a non – linear duty ratio D change is avoided. The whole system is simulated using Matlab/Simulink and some useful results are presented.

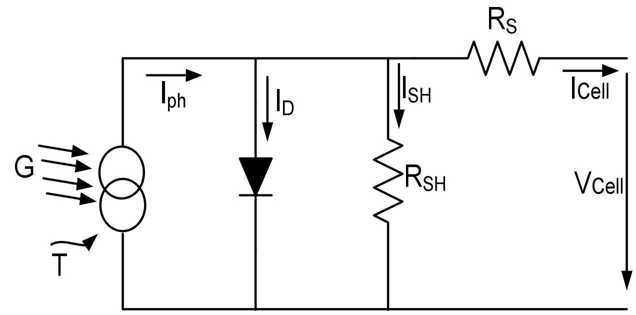



Fig. 1. PV cell equivalent circuit.

## II. Mathematical Model Of Photovoltaic

The simplest model of a PV cell consists of a current source in parallel connection with a diode as shown in figure 1.

Photo current $I_{ph}$ is directly proportional to solar radiation G. Temperature T and photo current $I_{ph}$ have a linear relationship according to equation (1), where $I_{ph(Tref)}$ is photo current which corresponds to reference temperature $T_{ref}$. Equation (2) gives photo current at reference temperature. $K_0$ is a constant given by (3). In equation (2) and (3) $G_{ref}$ is the nominal radiation given by PV's constructor and $I_{SC}$ is the short circuit current. All symbols are presented on figure 1 and used in equations refer to a single PV cell.

$$I_{ph} = I_{ph(T_{ref})} \cdot \left(1 + K_0 \cdot \left(T - T_{ref}\right)\right) \tag{1}$$

$$I_{ph(Tref)} = \frac{G}{G_{ref}} \cdot I_{SC(Tref)} \tag{2}$$

$$K_0 = \frac{I_{SC(T)} - I_{SC(Tref)}}{T - T_{ref}} \tag{3}$$

Diode's current is given by (4), where $V_{Cell}$ and $I_{Cell}$ are output voltage and current for a single PV cell respectively, $I_o$ is diode's saturation current, $V_T$ thermal voltage of it and $R_S$ is in series resistance.

$$I_D = I_o \cdot \left[ \exp\left( \frac{V_{Cell} + I_{Cell} \cdot R_S}{V_T} \right) - 1 \right] \quad (4)$$

Current $I_{SH}$ through shunt resistance $R_{SH}$ according to Ohm's law is equal to:

$$I_{SH} = \frac{V_{Cell} + I_{Cell} \cdot R_S}{R_{SH}} \quad (5)$$

Taking into account equations (1) – (5) and applying Kirchhoff's current law, I –V characteristic equation (6) is resulted for PV cell:

$$I_{Cell} = I_{ph} - I_o \cdot \left[ \exp\left( \frac{V_{Cell} + I_{Cell} \cdot R_S}{V_T} \right) - 1 \right] - \frac{V_{Cell} + I_{Cell} \cdot R_S}{R_{SH}} \quad (6)$$

Substituting in (6) equations (7) and (8) which gives output voltage V and current I respectively for Ns in series and Np in parallel PV cells and ignoring current through shunt resistance, equation (9) gives the general I – V characteristic for PVs. Equation (10) gives the output power of a PV module consisted of (Ns x Np) cells.

$$V = N_S \cdot V_{Cell} \quad (7)$$

$$I = N_P \cdot I_{Cell} \quad (8)$$

$$I = N_P \cdot I_{ph} - N_P \cdot I_o \cdot \left[ \exp\left( \frac{V + I \cdot \left( \frac{N_S}{p} \right) \cdot R_S}{N_S \cdot V_T} \right) - 1 \right] \quad (9)$$

$$P = (N_S \cdot N_P) \cdot V_{Cell} \cdot I_{Cell} \quad (10)$$

Equation (10) is able to be extended for a single PV array which consists of a number of PV modules and for a PV farm with many arrays.

## III. Algorithm Description And Operation

The proposed algorithm is very simple both in implementation and operation. It is based on "Hill Climbing" algorithm [8], [9], which controls the sign of P –V curve's slope in each calculation step and makes appropriate voltage changes.

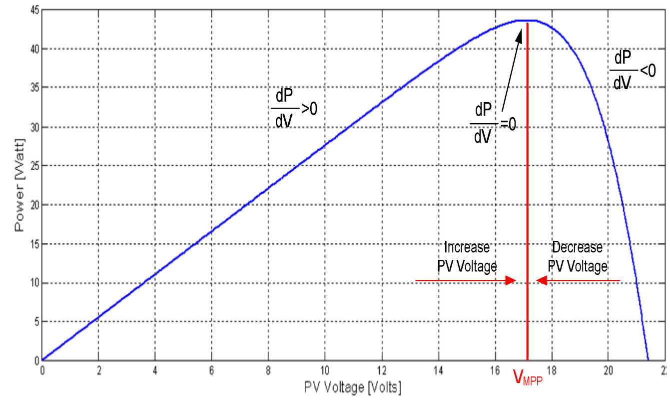



Fig. 2. PV Power vs. Voltage with essential voltage change for achieving operation in MPP.

### *A. Algorithm Description*

Figure 2 presents a typical Power versus Voltage curve. Basic and simple operation of "Hill Climbing" algorithm is shown on this one. Red line represents that point where slope is zero and PV maximum power is extracted. When slope's sign is positive a PV voltage increasing is essential in order to achieve operation in MPP. Similarly, a decreasing in PV voltage must be done in the case of a negative slope's sign.

Classic "Hill Climbing" algorithm can be operated both with a fixed and a variable voltage step change. During operation with fixed voltage step size, there is no need to control the way that step is changed. Otherwise, in operation with a variable voltage step size it is necessary to find a way for controlling it flexibly.

New MPPT method that presented in this paper, is actually a modification of classic "Hill Climbing" one. According to this, any P – V slope's sign control and dynamic step size selection are avoided. The only thing that needs to be done is to calculate cube of P – V characteristic curve slope and add this to previous value of PV voltage. As shown on figure 3 (where x – axis represents slope and y – axis desirable voltage change) this modified algorithm is based on a hyperbola relation between slope and voltage step change. This kind of relation allows selection of bigger voltage step changes when slope is big, while step size is smaller as slope tends to be zero. When slope becomes zero there is no voltage change. That means MPP operation has been achieved. Equations (11) and (12) describe the whole algorithm operation. In each calculation step cube of P – V curve's slope is calculated and result is added in previous PV voltage value $V_K$. Through this procedure not only the desirable voltage changing direction, but also the appropriate voltage step change $V_{ref}$ are resulted. Thus, no control operation is essential and the whole system is forced to operate under new voltage $V_{K+1}$.

$$V_{ref} = \left( \frac{\partial P}{\partial V} \right)^3 \quad (11)$$

$$V_{K+1} = V_K + V_{ref} \quad (12)$$

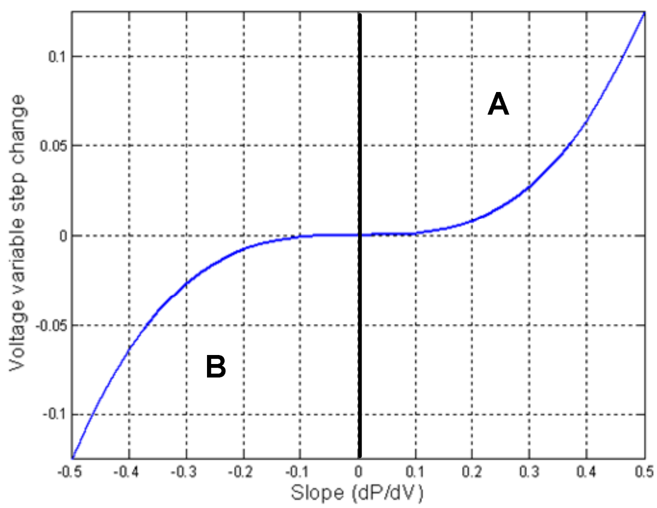



Fig. 3. Hyperbola relation between slope and voltage variable step change.

In order to avoid $V_{ref}$ of taking very big values, which may brings out extended oscillations around MPP and MPP achieving in many calculation steps, a limiter is used. By setting upper and lower limits (for example 5% of total PV open circuit voltage), that problems are avoided.

Equation (11) refers to a single PV array, but can be extended for Np in parallel and Ns in series arrays. Mathematical analysis has been done, results equation (13), which gives desirable voltage step change for a (Np x Ns) PV farm. Figure 4 is shown proposed method's flow chart.

$$V_{ref} = N_P \cdot \left( \frac{\partial P}{\partial V} \right)^3 \tag{13}$$

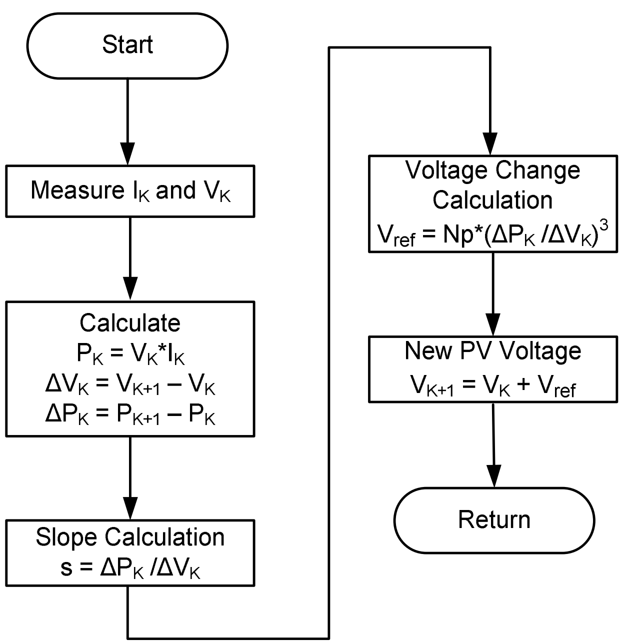



Fig. 4. Flow chart of the proposed method.

## B. *Algorithm Application on Buck – Boost DC/DC Converter*

Buck – Boost DC/DC converter (figure 5) has been chose for new MPPT algorithm application due to some disadvantages that occurs on control. The most important of these is the non – linear behavior of output voltage versus input one, if duty ratio is changed in a linear way. Equation (14) gives the relation between input $V_{in}$ and output $V_{out}$ voltage for a buck – boost DC/DC converter. As shown, a linear control of input voltage by assuming fixed output, can be occurred only if the whole ratio D/(1 – D) is controlled linearly and not the duty ratio D individually. By replacing the whole ratio D/(1-D) with a new variable d, figure 6 presents this non – linear relation between d and D. In [10] the control focuses on this new variable d, but in this paper duty ratio D is controlled through PV voltage. That means, once new desirable voltage was calculated in each step, new duty ratio is resulted from equation (15). In this equation, $V_{out}$ represents converter's output fixed voltage, while $V_{in}$ the new estimated value of input voltage $V_K$.

According to figure 6, an almost linear relation between duty ratio D and d is occurred when D is less than 0.5, but it becomes non – linear for values greater than 0.5. A direct duty ratio control would bring a non – linear behavior of MPPT controller, especially in boosting operation. This non – linear behavior is responsible for tracker's oscillations around MPP and whole system unstable.

$$V_{out} = \frac{D}{1-D} \cdot V_{in} \tag{14}$$

$$D = \frac{V_{out}}{V_{out} + V_{in}} \tag{15}$$

## IV. Simulation Results

A PV farm consists of 10 in parallel and 20 in series rows of PV arrays, has been simulated using Matlab/Simulink. From each array can be extracted 50W of power. Thus, total nominal power of the whole PV farm is 10KW. Table I includes PV arrays' characteristics. Simulations have been done both for classic "Hill Climbing" algorithm with a fixed step size and for new proposed method under rapidly changed atmospheric conditions. In this paper as rapidly changed condition is used an increase from 400 W/m$^2$ to 500 W/m$^2$ of solar radiation.

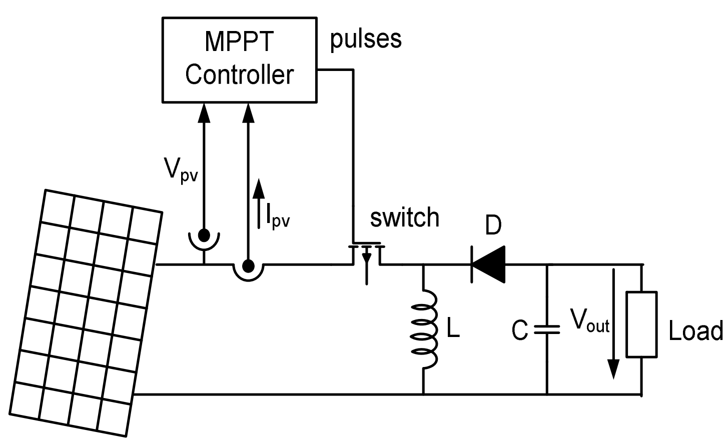



Fig. 5. Buck – Boost DC/DC Converter

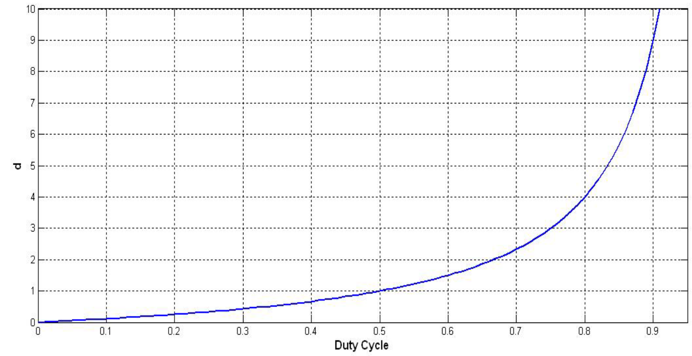


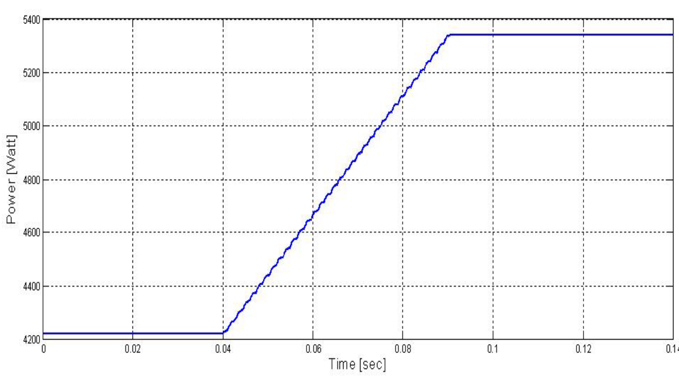

Fig. 6. Duty ratio vs. d. A non – linear relation is occurred.

TABLE I
CHARACTERISTICS FOR A SINGLE PV ARRAY

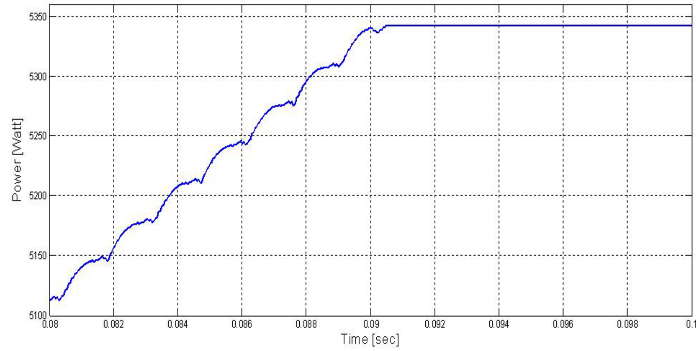
| | |
|---|---|
| Open circuit voltage at 1000W/m^2, Voc | 21.7 V |
| Short circuit current at 1000W/m^2, Isc | 3.45 A |
| Maximum power at 1000W/m^2, Pmax | 50 W |
| MPP voltage at 1000W/m^2, $V_{MPP}$ | 17.24 V |
| MPP current at 1000W/m^2, $I_{MPP}$ | 2.91 A |

Simulation results using new MPPT method are shown in figures 7 and 8. In figure 7(a) PV output power versus time is presented, while in (b) a better view of ripple for a specific area is shown. Operation of tracker and oscillations around MPP are presented on figure 8. On this figure, lower curve represents solar radiation equal to 400W/m$^2$ and upper one 500 W/m$^2$.

Model simulation has been done using classic "Hill Climbing" algorithm for fixed step size. Two different voltage steps were used, one equal to full and the other to half of limit in step size limiter taken into account in new method simulation. Figures 9 and 11 present extracted power form PV arrays versus time for two voltage step mentioned above. From these figures is shown that power ripple using classic algorithm is bigger than the proposed one. A better view of this ripple can be seen on figures 9 (b) and 11 (b). This means loss of energy during transition and unstable operation. A comparison also is able to be done by considering figures 10 and 12 which present tracker's operation. As shown on these, oscillations around MPP are much bigger in the case of fixed steps than using new method.




(a)




(b)

Fig. 7. (a) Power vs. response time for rapidly changed conditions using the proposed method (b) zoom of a specific area from (a).

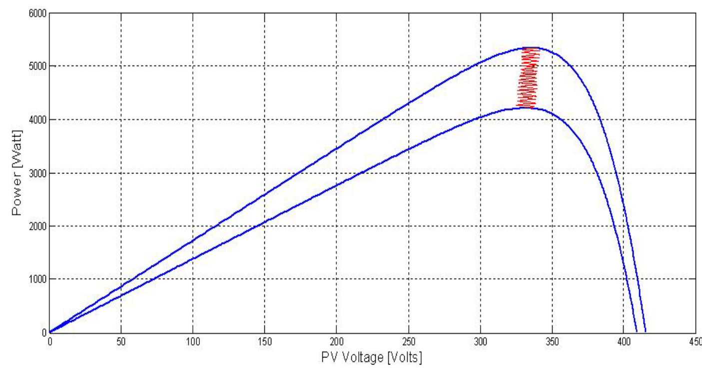
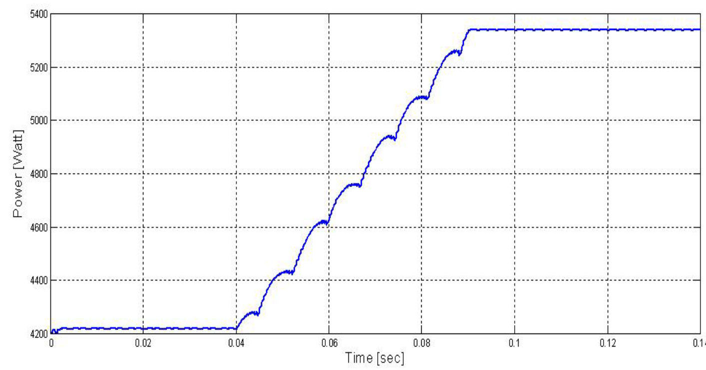
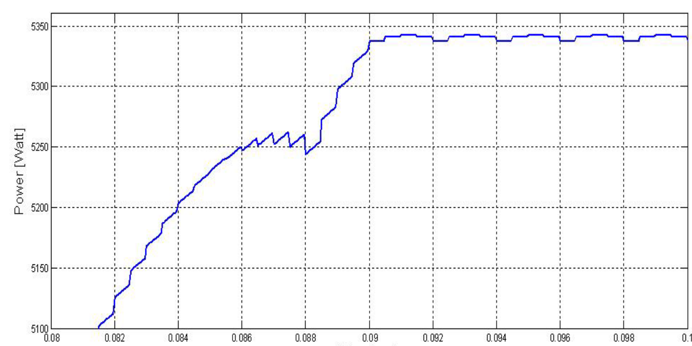



Fig. 8. Tracker operation for rapidly changed conditions using the proposed method.




(a)




(b)

Fig. 9. (a) Power vs. response time for rapidly changed conditions using classic "Hill Climbing" algorithm with fixed voltage step equal to half of limit (b) zoom of a specific area from (a).

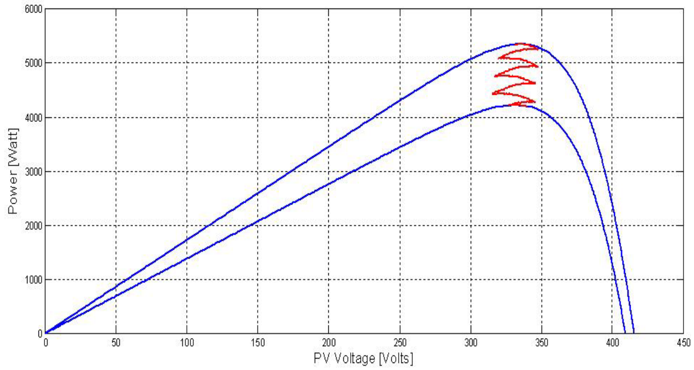
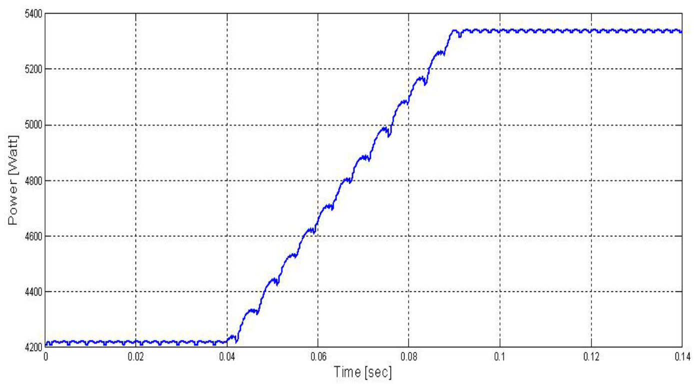
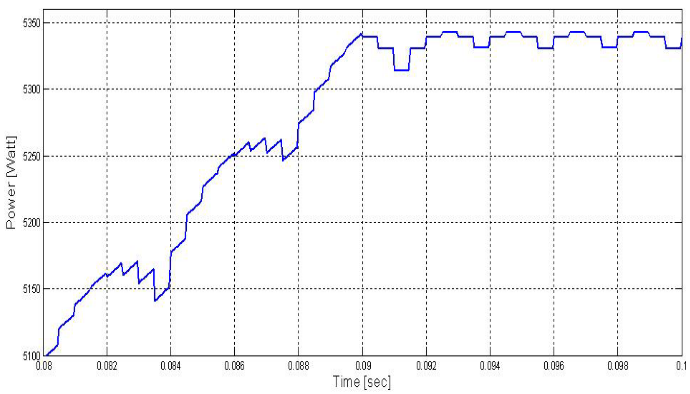



Fig. 10. Tracker operation for rapidly changed conditions using classic "Hill Climbing" algorithm with fixed voltage step equal to half of limit.




(a)




(b)

Fig. 11. (a) Power vs. response time for rapidly changed conditions using classic "Hill Climbing" algorithm with fixed voltage step equal to full limit (b) zoom of a specific area from (a).

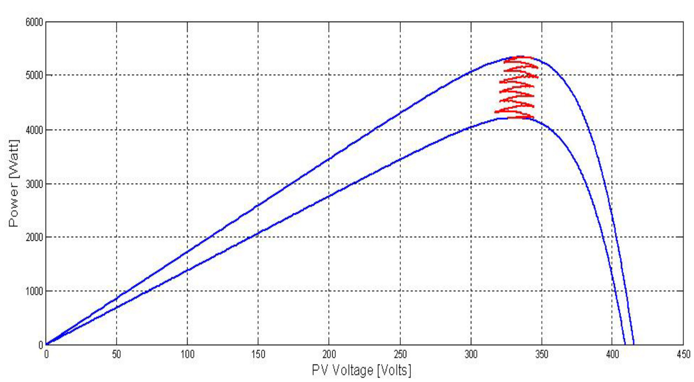



Fig. 12. Tracker operation for rapidly changed conditions using classic "Hill Climbing" algorithm with fixed voltage step equal to full limit.

## V. CONCLUSION

This paper presents a new method for MPPT which is based on classic "Hill Climbing" algorithm. Proposed method selects a variable voltage step change according to P – V curve's slope. Buck – Boost DC/DC converter is used for new method application due to the wide range of output voltages supports. An indirect duty ratio control through input voltage change is proposed in order to avoid non – linear behavior of MPPT. So, this method is more flexible and due to its flexibility, results power ripples elimination both in steady state and during transitions. Taking into account this, more energy is extracting from this PV system during the same time period. One more advantage of this proposed method is the simpleness of its implementation.

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