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A NEW CONTROLLING METHOD FOR MAXIMUM POWER POINT TRACKING IN PHOTOVOLTAIC SYSTEMS

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Abstract- Due to the variable, stochastic behavior of the solar energy resource, Maximum Power Point Tracking (MPPT) of photovoltaic (PV) is required to ensure continuous operation at the maximum power point to generate the most electrical energy. Also, high cost of photovoltaic systems necessitate to get them in high efficiency utilization systems Among existing methods for maximum power point tracking (MPPT), Incremental conductance method by having a relatively high speed and accuracy is unable to make a good compromise between radiation and ambient temperature. In this paper, in addition to improving the Incremental conductance method, a new and robust method based on model predictive control (MPC) is presented to trace and extract the current, corresponding to the maximum power point. This method is real-time method so the results of simulation confirm the speed and accuracy of this method.

Keywords: Photovoltaic, MPPT, MPC, Converter.

I. INTRODUCTION

The reduction in the cost of photovoltaic cells has further increased interest in renewable energy source, which continues to gain popularity with 60% annual growth in the installed capacity of photovoltaic (PV) systems from 2004 to 2009, and 80% in 2011. High cost of photovoltaic systems and nonlinearity of Output characteristics of photovoltaic arrays with radiation and temperature has caused getting them by adequate control methods and power electronic converters in order to have a cost effective system.

In order to achieve to the maximum power point of photovoltaic arrays, the system should reach to an equilibrium at the maximum power point, so whit this goal, designers of these systems use DC/DC converters. Since the characteristic curve of photovoltaic cells depends on the radiation from the sun and the cell temperature. Therefore, the maximum power point of the array will be changed. In addition, the operating point of all loads at all levels of temperature and radiation is far from the operating point of array maximum power which prevents the use of the maximum output power of the array.

As a result, achieving an optimal fit in all the radiation and temperature can be difficult unless it can be used in the design of an optimal matching system. Hence, in order to improve the performance of these systems designers use DC-DC converters. This system can continuously adjust the input of load with the maximum power produced by the panels. Matching load with solar plans by maximum power point tracking (MPPT) controllers, affects the system performance and increase the system efficiency.

Generally photovoltaic systems by a DC/DC converter, battery and one inverter connect to system [1]. In recent years, there has been an increasing interest in the integration of Distributed Generation (DG) systems based on renewable energy resources to the distribution grid, which consider different objectives, such as technical [2], economical [3, 4], and environmental [5] aspects. It is estimated that the share of these resources (e.g., wind turbines, photovoltaic, fuel-cells, biomass, micro-turbines, small hydroelectric plants, and etc.) in electrical networks will increase significantly in the near future [6, 7].

In parallel, the progress in technology has led to more powerful systems. Application of renewable energy resources in a power system may cause major changes in the design and operation of distribution grids [8]. Moreover, the environmental advantages, the shorter construction period can also be considered as a key driving element accelerating the development of DG technology [9]. Multilevel converters, are a good tradeoff solution between performance and cost in high-voltage and high-power systems. The main advantages of multilevel converters are reduced voltage ratings for the switches, good harmonic spectrum (making possible the use of smaller and less expensive filters), and good dynamic response [10]. However, the control complexity increases compared to conventional voltage source inverters (VSI). So, practical, cost effective, and flexible control strategies are vital to grid connection of renewable energy resources to the distribution grid.

Solar cells convert solar energy into electrical energy. This phenomenon occurs in materials which have the property of capture photon and emit electrons. The main material used in the photovoltaic industry is silicon. But there are many lines of research to find materials to replace or supplement to silicon to improve conversion efficiency, as for example [11, 12]. The Photovoltaic system connected to the network and its control diagram is shown in Figure 1. Numerous methods for maximum power point tracking (MPPT) are proposed, some of these methods are:

1- Fraction of short circuit current and open circuit voltage: in this method separating array from system required for measuring the short circuit current and open circuit voltage that results to wasting the amount of power.

2- Hill climbing (HTC), these method operates based on alternating the time periods of power converter [13].

3- Perturbation and observation, in this method, there are always steady-state oscillations owing to different disturbance though changing of the two methods 2 and 3 [14].

4- Incremental Conductance (INC): This method is based on changes of zero point of power of array depending on the voltage at the maximum power point. In this method accuracy and speed of maximum power point tracking under sudden changes in environmental condition is relatively improved [15, 16]. This method is based on changes in the zero of array power and voltage at the maximum point of power.

5- Neural Networks [17, 18].

6- Fuzzy logic [19, 20].

In this paper presented method is based on model predictive control (MPC) [21, 22], and results of simulations confirms the speed and accuracy of this method.

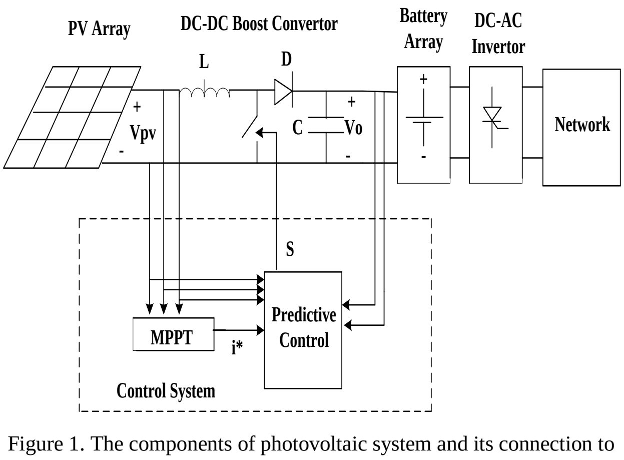

Figure 1. The components of photovoltaic system and its connection to distribution network.

II. CURRENT-VOLTAGE CHARACTERISTIC OF PHOTOVOLTAIC ARRAYS

Figure 2 shows two-diode equivalent circuit of one solar cell [12].

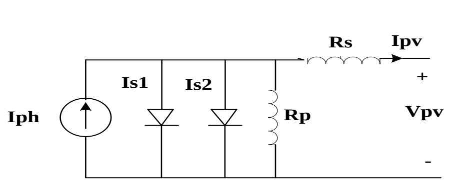

Figure 2. The two diodes equivalent circuit of solar cell

In this circuit I_{s1} and I_{s2} are Saturation current of diodes, I_{ph} is short circuit current and R_p & R_s are parallel and series resistances. The current-voltage characteristic equation of presented solar cell is related by the Equation (1):

$$I = I_{ph} - I_{s1}\left\{\exp(\frac{V+R_sI}{n_1V_t})-1\right\} - I_{s2}\left\{\exp(\frac{V+R_sI}{n_2V_t})-1\right\} - \left(\frac{V+R_sI}{R_p}\right) \tag{1}$$

Information relating to the above equation is available in reference [12]. Also dependency of *V-I* characteristic of solar cell to temperature and radiation is can be related by the Equations (2) and (3):

$$\begin{cases} I_{ph}(s) = I_{ph}\cdot\left(\dfrac{S}{S_{ref}}\right) \\ I_{ph}(TC) = I_{ph}\left\{1+T_{Ip1}(T_c-T_m)\right\} \end{cases} \tag{2}$$

$$\begin{cases} R_s(T_c) = R_s\cdot\left(\dfrac{T_c}{T_m}\right)^{T_{Rs}}, \quad R_p(T_C) = R_p\cdot\left(\dfrac{T_c}{T_m}\right)^{T_{Rp}} \\ I_{si}(T_c) = I_{si}\left(\dfrac{T_c}{T_m}\right)^{c_i}.\exp\left\{E_G(\dfrac{T_c}{T_m}-1)/n_iV_t\right\} \\ C_i = \dfrac{T_{Isi}}{n_i} \end{cases} \tag{3}$$

In above equations $T_{Rp}, T_{Rs}, T_{Is1}, T_{Is2}, T_{If1}$ are dimensionless thermal coefficients of resistances and currents of cells and have a specific and constant values for each cell [23]. In order to increase output voltage and current and as a consequence power raise, cells should be connected in series and parallel, respectively. A combination of 25 solar cells in this paper is used as Table 1.

Table 1. Characteristics of Photovoltaic arrays

Parameter	Value
I_{SC}	3.7 [A]
V_{OC}	22 [V]
I_{MPP}	3.47 [A]
V_{MPP}	18.7 [V]
P_{MAX}	65 [W]
T_{Isi}	3

III. MAXIMUM POWER POINT TRACKING (MPPT) BY IMPROVING INCREMENTAL CONDUCTANCE METHOD

The controller task in maximum power point tracking is transferring the operating point of arrays to the knee point of current-voltage curve. Reception the feedback signal of light intensity and temperature of the array is not a simple work, so such methods should be used that controller without the feedback signal of light intensity and temperature of the array be able to provide adequate outputs for maximum power point tracking.

In this paper, incremental conductance method because of sufficient response speed to fast climate changes, is used. In the maximum power point, power changes with voltage is zero $(\frac{dp}{dv}=0)$.

Therefore, it can be written as follow:

$$dp/dv = d(iv)/dv = i + v.di/dv = 0 \quad (4)$$

when $\frac{dv}{di} = -\frac{v}{i}$, the ratio of power changes to the voltage changes will be zero and this point is the maximum power point. In Figure 3, the algorithm of improved incremental conductance method is shown, where, k is the sampling time at t; k-1 is the sampling time at the previous Δt, i^* is reference current of model predictive controller (MPC), which is result of changes in transient current ($I_L(k)$) not from changes of reference current in a moment ago $-I^*(k-1)$(the reference current), this change in reference current gives this ability to system for faster tracking of maximum power with bigger steps. This change makes the system be able to track the maximum power with higher speeds (i_{inc}).

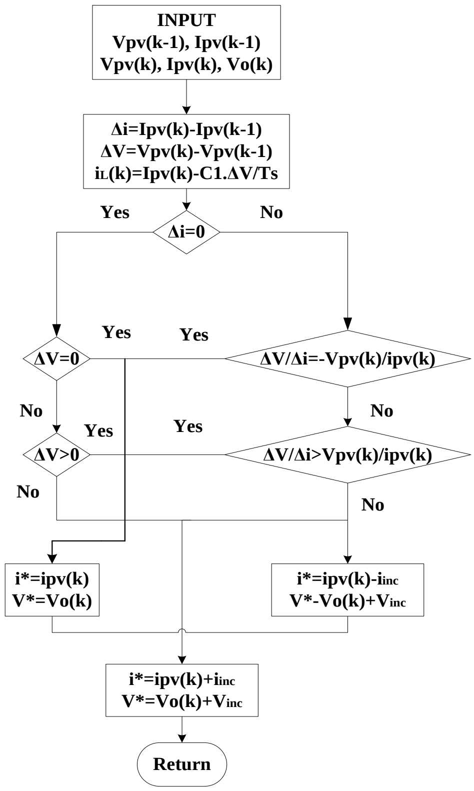

Figure 3. The conductance algorithm flowchart of improved incremental method

IV. DC/DC BOOST CONVERTOR, DESIGN AND IMPLEMENTATION MODEL PREDICTIVE CONTROLLER

In Figure 4, structure of this converter in two state, open switch (s=1) and closed switch (s=0) is shown, corresponding equations to the equivalent circuit of this models related in Equations (5)-(10).

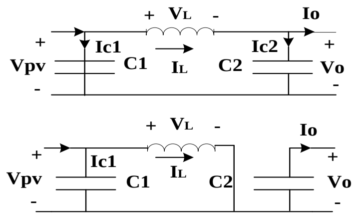

Figure 4. The equivalent circuit of DC/DC boost convertor

- Open switch (s=1):

$$\frac{di_L}{dt} = \frac{v_{PV}}{L} - \frac{v_O}{L} \quad (5)$$

$$\frac{dv_{PV}}{dt} = -\frac{i_L}{C_1} + \frac{i_{PV}}{C_1} \quad (6)$$

$$\frac{dv_O}{dt} = \frac{i_L}{C_2} - \frac{v_O}{RC_2} \quad (7)$$

- Closed switch (s=0):

$$\frac{di_L}{dt} = \frac{v_{PV}}{L} \quad (8)$$

$$\frac{dv_{PV}}{dt} = -\frac{i_L}{C_1} + \frac{i_{PV}}{C_1} \quad (9)$$

$$\frac{dv_O}{dt} = -\frac{v_O}{RC_2} \quad (10)$$

Discretization of continuous-time Equations (5)-(10), by sampling T_s, is expressed as fallowing relations:

$$i_L(k+1) = i_L(k) + \frac{T_s}{L} v_{PV}(k) - \frac{T_s}{L} v_O \quad (11)$$

$$v_{PV}(k+1) = -\frac{T_s}{C_1} i_L(k) + v_{PV}(k) + \frac{T_s}{C_1} i_{PV}(k) \quad (12)$$

$$v_O(k+1) = \frac{T_s}{C_2} i_L(k) + (1 - \frac{T_s}{RC_2}) v_O(k) \quad (13)$$

$$i_L(k+1) = i_L(k) + \frac{T_s}{L} v_{PV}(k) \quad (14)$$

$$v_{PV}(k+1) = -\frac{T_s}{C_1} i_L(k) + v_{PV}(k) + \frac{T_s}{C_1} i_{PV}(k) \quad (15)$$

$$v_O(k+1) = (1 - \frac{T_s}{RC_2}) v_O(k) \quad (16)$$

Also equation of discrete-time boost converter can be summarized in the fallowing matrix format:

$$\begin{bmatrix} i_L(k+1) \\ v_{PV}(k+1) \\ v_O(k+1) \end{bmatrix} = \begin{bmatrix} 1 & \frac{T_s}{T_L} & -\frac{T_s}{L} \\ -\frac{T_s}{C_1} & 1 & 0 \\ s\frac{T_s}{C_2} & 0 & (1-\frac{T_s}{RC_2}) \end{bmatrix} . \begin{bmatrix} i_L(k) \\ v_{PV}(k) \\ v_{O(k)} \end{bmatrix} . \quad (17)$$

$$. \begin{bmatrix} 0 & \frac{T_s}{C_1} & 0 \end{bmatrix}^T . i_{PV}(k)$$

According to Equation (17), in the next sampling step (k+1), control variables (v_O, i_L, v_{PV}) can be predicted. The defined cost function J, is expressible for two state (open switch and closed switch) in Equation (18).

$$J^1_{s=0,1} = \omega_A . \left| v_O(k+1)_s - v^* \right|^2 + \omega_B \left| i_L(k+1)_s - i^* \right|^2 \quad (18)$$

The flowchart of the proposed algorithm is illustrated in Figure 5, where, J is the cost function of reference current and voltage of INC algorithm and control variables of MPC algorithm, ω_A and ω_B are the penalty coefficients of error in voltage and current, and their dimensions are [1/V] and [1/A], respectively. In MPC method it is possible to increase control drop up to n, in this case discrete-time Equations (11)-(16) can be rewritten to Equations (19)-(21).

$$i_L(k+n+1) = i_L(k+n) + \frac{T_s}{L} v_{PV}(k+n) - s\frac{T_s}{L} v_O(k+n) \quad (19)$$

$$v_{PV}(k+n+1) = -\frac{T_s}{C_1} i_L(k+n) + \\ + v_{PV}(k+n) + \frac{T_s}{C_1} i_{PV}(k+n) \quad (20)$$

$$v_O(k+n+1) = (1 - \frac{T_s}{RC_2}) v_O(k+n) \quad (21)$$

If control drop considered to 2, the cost function is modified as follows:

$$J^2_{s=0,1} = \omega_A . \left| v_O(k+2)_s - v^* \right|^2 + \\ + \omega_B \left| i_L(k+2)_s - i^* \right|^2 + J^1_{s=0,1} \quad (22)$$

In above equation $J^1_{s=0,1}$ is cost function one step ahead and the voltage in Equation (22) corresponds to two steps ahead (k+2). Figure 6 shows the case in that, control drop is set to two.

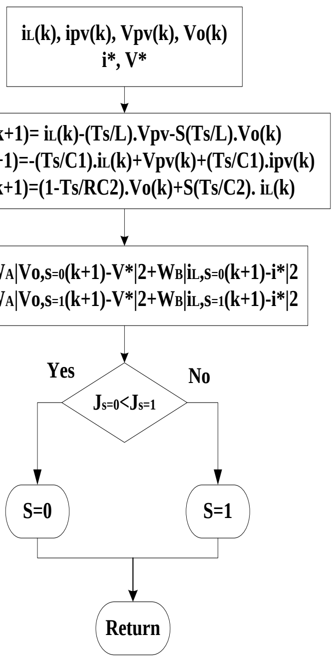

Figure 5. Algorithm flowchart of model predictive control to control the convertor switches

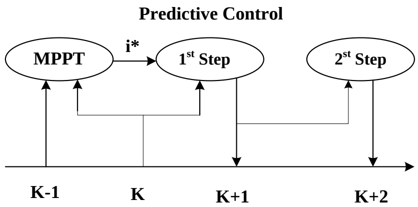

Figure 6. The time arrangement between MPC and MPPT

V. SIMULATION RESULTS

In order to prove the capability of presented method versus changes in radiation intensity (W/m^2), a pulse function (Figure 7) which applies sudden changes to photo voltaic system from 700 to 1000 and from 1000 to 900 is considered. According to the obtained results presented in Figures 8-11, the MPPT algorithm tracks the new values of maximum power. In each case, the power extracted from the PV is well controlled. The results prove that the convergence speed is relatively high. The power changing, current, voltage and maximum power of the array via applying the radiation function are respectively depicted in Figures 8-11. According to the obtained results, the tracking efficiency is not less than 93%. Therefore, the proposed method guarantees good tracking efficiency under different operating conditions.

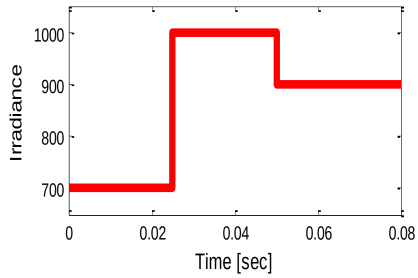

Figure 7. Sudden changes in radiation in simulation environment to consider the model predictive control method

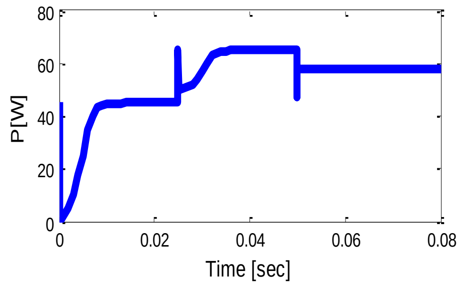

Figure 8. Tracking the maximum power point of array under sudden radiation changes

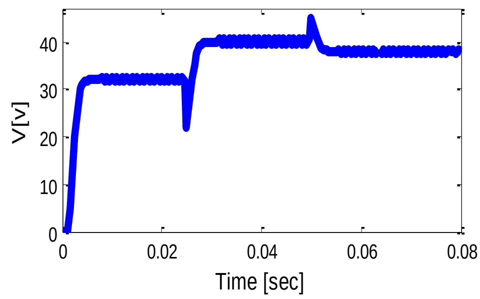

Figure 9. Changes in load voltage to receive maximum power under fast changes of radiation

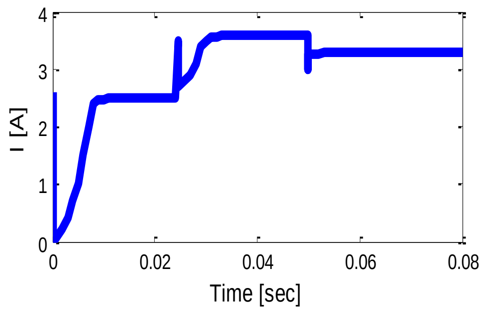

Figure 10. Changes in array current to receive maximum power under fast changes of radiation

Load Changes cause displacement in operating system point, and as a consequence reduction in output power of arrays, designed controller should have capability of maximum power point tracking in case of load changes. So to test the capability of model predictive control (MPC), a photovoltaic system by time varying load (Figure 11) is considered. the result of changes in power, voltage, current for extracting maximum power in case of changes in connected load to system from 25 Ω to 30Ω and then to 25 Ω, are shown in Figures 12-15. Also, the global MPP 65.77 [W] is tracked.

Some main advantages of the proposed control method MPP tracker are as follows:

✓ The proposed MPC tracker is naturally robust to environmental (e.g., insolation, temperature and aging) and parameter variations.

✓ The proposed tracker does not require any external sensor or a dummy solar panel for detecting temperature and solar intensity.

✓ The proposed control method tracker has fine performance for different load types (R, L, C, RL, RC, etc.) since the performances of MPC controllers are not load dependent.

The Parameters of model predictive controller and boost converter are presented in Table 2.

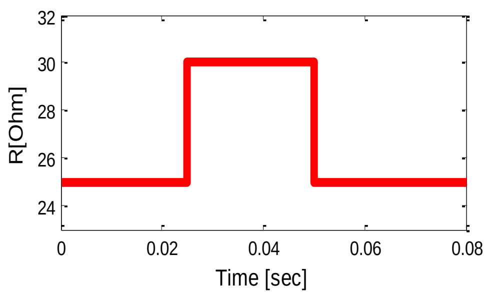

Figure 11. Changes in connected load to system

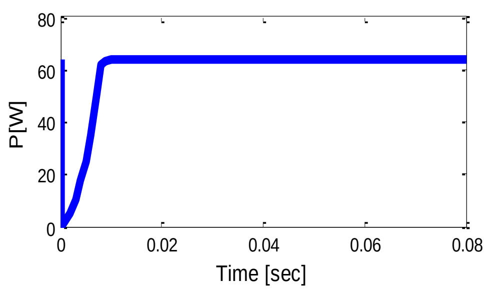

Figure 12. Tracking the maximum power point of array under changes in connected load to system

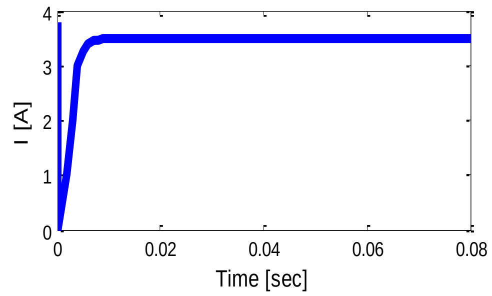

Figure 13. Changes in array current to receive maximum power under changes in connected load to system

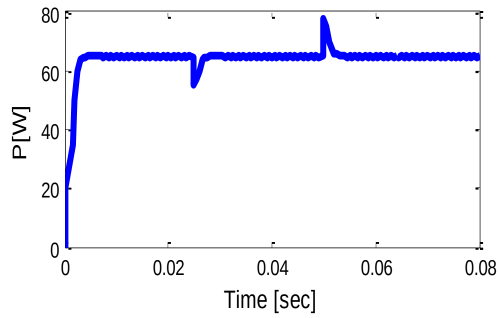

Figure 14. The maximum receive power tracking under load variation

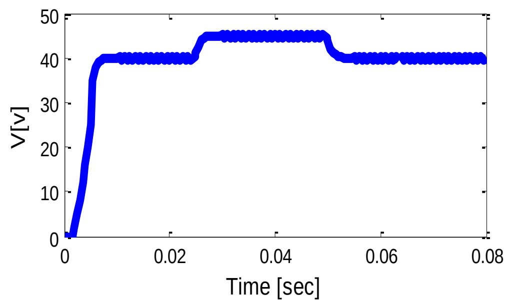

Figure 15. Changes in array voltage to receive maximum power under changes in connected load to system

Table 2. Parameters of model predictive controller and boost converter

Parameter	Value
C_1	10 [μF]
C_2	100 [μF]
L	20 [mH]
T_S	10 [μs]
W_A	3
W_B	25
i_{inc}	0.15 [A]
v_{inc}	0.1 [V]

VI. CONCLUSIONS

In this paper a new method based on model predictive control for maximum power point tracking presented and the results of this method conforms the high response speed and high accuracy of this method for maximum power point tracking to fast changes in climate and load condition. Based on results of presented simulation, by applying these changes to system, system will be stabilized by low settling time.

A practical case developed in a Matlab/Simulink simulation platform has been presented, and the results confirm the adequate performance of designed control. So, the dynamical response of the control is around one period of the voltage supply. Besides, the control law can be easily implemented by means of standard operational amplifiers, analog multipliers and digital devices in an experimental platform. The proposed control method has the ability to be used in all types of converters topologies and can be used for different types of renewable energy resources as power quality improvement devices in a customer power distribution grid.

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BIOGRAPHIES

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