International Journal of Latest Engineering and Management Research (IJLEMR)
ISSN: 2455-4847
www.ijlemr.com ‖ Volume 1 - Issue 8 ‖ September 2016 ‖ PP. 41-48

MPPT CONTROLLER USING SLIDING MODE CONTROL SCHEME FOR STAND ALONE PV SYSTEM

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Abstract- This paper proposes the Maximum Power Point Tracking using Sliding Control scheme (SMC) for Stand Alone Photo voltaic (PV) System. The main objective of this controller is to enhance efficiency of the PV power system. &to achieve an optimum MPP operation without the need of atmospheric condition measurement. The proposed controller overcomes the problem of the power oscillation around the operating point which appears in most implemented MPPT techniques. The proposed MPPT controller uses SMC has been developed in such a way that the sliding surface is set to be the optimum operating point. An Adaptive SMC gain has been designed and implemented in the proposed controller to allow the compensation of the uncertainty of ambient conditions. The result shows a satisfactory operation of a PV power system& better availability of the operating point to the optimal operating point. The validation of the proposed controller is shown by MATLAB/SIMULINK simulation. Moreover Classical MPPT algorithm using incremental condition has been developed for the same PV power system in order to evaluate the proposed SMC controller. A comparison analysis of the proposed controller with incremental condition algorithm has been undertaken and result in noticeably better reachability of the proposed SM controller.

Index Terms- Adaptive SMC gain, Maximum power point tracking, PV control, sliding mode control, Solar power system.

1. INTRODUCTION

Recently, in standalone configuration, the solar energy applications are getting increased. It is considered as one of the promising source of renewable energy. It has become very much necessary to obtain MPP operation, because of the limitation of PV energy system like low efficiency and the non linearity of the output characteristics. The output of the PV panels [1] gets affected due to variation on solar irradiance levels, ambient temperature and the dust accumulation on the PV panels.

The main objective of MPPT technique is to automatically obtain an optimal MPP operation under variable atmospheric condition. Many MPPT techniques have been developed for PV system, the widely used algorithms are Incremental condition and perturbation and observation (P&O) algorithms. The logic of most of the algorithm are similar. In P&O, the perturbation is made in the operating point till maximum power achieved. On other hand, in IC, the P-V curve slope of the PV system is checked till it reaches zero at which the MPP operation is achieved[1]. Another MPPT technique used for PV System is the constant voltage algorithm, in which the MPP operation achieved by keeping the ratio between the PV voltage at the maximum power and open circuit voltage constant [2].

Most of the above discussed MPPT methods are widely used because they are independent of atmospheric measurements and the ease of implementation, but they also suffers with the drawback that the power oscillation and around MPP which is caused by fix perturbation step size Another drawback is that the confusion in the direction of tracking which is caused by rapidly changing atmospheric conditions[3],[4],[5] provides a solution of the fixed iteration size by introducing variable iteration size varies according to the operating point.

Recently, due to the benefits of quick response and robustness[6], sliding mode control has received many attentions.SMC can be defined as a variable structure control strategy based on the feedback & high frequency switching control[7]. SMC has many merits such as insensitivity to system parameter changes, disturbance and load variations [8]. The two main stages of SMC design [9] are, achieving the design of stable sliding surface &obtaining optimum design of a control flow, which forces the operating point to reach a predetermined surface in finite time. SMC requires maintaining a constant gain so that a robust & finite time convergence of the sliding boundary is achieved. Steady state error [6], [10],[11]might introduce when using constant gain. In a PV system [12]-[14] with SMC, there may be lake of robustness due to the use of reference current. Similar approach has been reported in [15] where the sliding surface has been selected to fallow the incremental condition. The energy conversion efficiency and steady state errors may be resulted due to SMC gain was set to be constant..

In this proposed MPPT controller of PV system developed using SMC. The sliding surface is designed to be the condition of MPP, so that the operating point converges to the optimum operating point..An adaptive SMC gain is designed to allow the compensation of the uncertainty of ambient condition.

II. PV POWER SYSTEM AND CHARACTERISTICS.

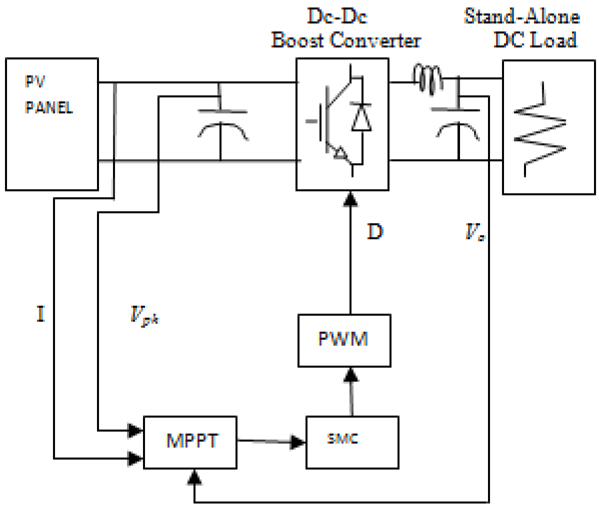

Fig.1.Implemented PV system and Control Diagram .

The PV power system implemented in this research consists of PV panel, with a rated power of 85W at ambient temperature of 25^0 C and solar radiation of $1000w/m^2$, connected to a stand-alone load through DC-DC boost converter. The boost converter has been designed to operate at continuous conduction mode. Fig.1 illustrates the implemented PV system and the control diagram.

A. PV Characteristics

A PV module is a combination of series & parallel solar cells, which generates voltage and currents. In darkness, PV cell generates only currents as it becomes a PN junction diode [1]. A Mathematical model has been developed based on the equivalent circuit of a solar cell, in order to simulate the behavior of a PV system. Figure.2. Illustrates the equivalent circuit of a solar cell where I_{ph} is the photocurrent of the cell, V_{pv} and I_{pv} are the PV voltage and current respectively.

The series Resistance (R_s), which is very small and the shunt resistance (R_{sh}), which is very large, both can be selected to simplify the model[16]. The PV Panel can be described as the following [17].

$I_{pv}=I_{ph}-I_{sat}[\ ]$…….…………..(1)

$I_{ph}=[Isc_{+}K_f\ (T-25)]$ ………………. (2)

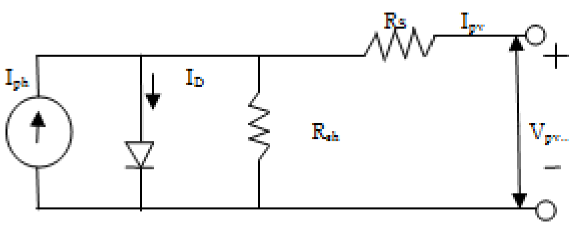

Fig .2: Equivalent Circuit of Solar cell

Where q is the charge of an electron($1.602x10^{-19}$ C),λ is a solar irradiance, A is the idealist factor of a p-n junction(1 or 2), k is a Boltzmann factor($1.381x10^{-23}$J/K).T is the temperature of the cell array and I_{sc} and K_f are the short circuit current temperature respectively. The output power characteristics of the PV panel as function of solar irradiance is shown in fig.3

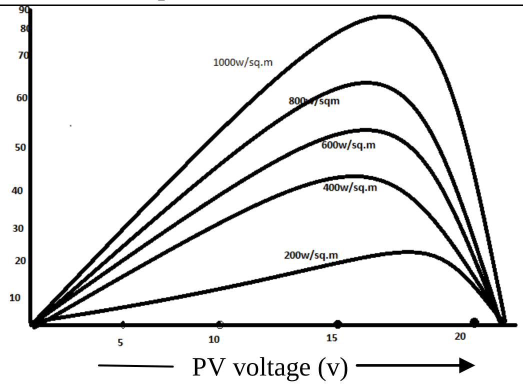

Fig.3:P-V curve of the PV Panel

B.DC-DC Boost Converter

DC-DC boost Converter is a type of converters used in application that require an output voltage to be higher than input voltage. DC-DC boost converter consists of an IGBT switch, a diode and passive components that are capacitor(C), Inductor(L) and resistance(R).The Boost converter operator consists of two states: On state in which IGBT switch is fired and OFF state in which the switch is turned off. The following equation describe the DC-DC boost converter operators [1]:

ON State

$L = V_{pv},$

$C + = 0$…..…………………...……… (3)

OFF State

$L + V_o = V_{pv}$

i_L-C-=0 …………………………………. (4)

The Ratio of the ON and OFF times to the operation time can be modulated using several techniques and is called as pulse width modulation (PWM).In this paper the duty ratio which is the control signal is compared to a triangular pulse. The control of boost type DC-DC converter is more difficult than the Buck type DC-DC converter. The difficulties come from the appearance of the control input in both voltage and current equations [18].

III PROPOSED MPPT CONTROLLER USING SMC

The boundary that a controller forces operation points to lie on can be defined as a sliding surface and can be presented as fallows [6],[19]

S(x) = (……………………………...…. (5)

$e = x_{ref} - x$ ………………………………………….. (6)

Where is a positive constant matrix, n is the relative degree, which is the number of differentiation until the control indices appear, e an error between a reference value (x_{ref}) and a controlled variable (x).

The structure of SMC (u) includes two parts, one is concerned with the linearization and the second part is to stabiliser which insures the stability of the SM controller. To analyse the motion in the sliding mode, equivalent control approach is used.. In this approach the discontinuous control, which makes the sliding surface s(x) approach 0 is replaced by an equivalent control. This equivalent control is obtained by setting s(x)=0 for the investigated system[6],[9]. The structure of such controller is expressed as:

$u = u_{eq} + u_n$.. (7)

where u_{eq} is the equivalent control element and is calculated along sliding mode as below, where K represents a positive constant.

S(x)=0.

u_n = -K sgn(s), sgn(s) =..................................(8)

The principle of proposed MPPT controller can be illustrated in fig4. The SMC controller will force the operating point at the top of the curve where the condition of maximum power is achieved. The Sliding surface has been selected to be the condition at which the MPP occurs and the controller design equations can be shown as the following:

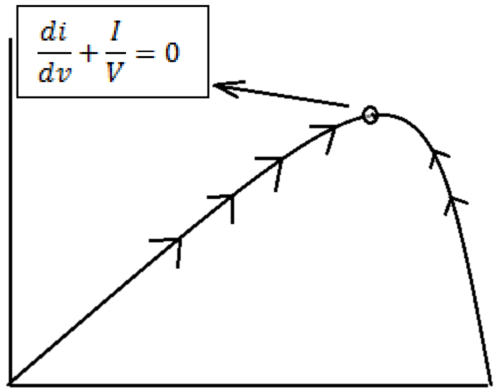

Fig.4: Condition for maximum power

s = e =0.. (9)
e = ,... (10)
. ... (11)
Solving the DC-DC boost converter equation 3 and 4 with respect to the ON and OFF states, the rate of change of inductor current (I_L) and the output voltage (V_o) can be shown as follows:
, ... (12)
.... (13)
The rate of change of inductor current with respect to the output voltage can be calculated by dividing the two equations as below:

.... (14)
Rearranging (14), the equivalent part of the SM controller can be represented in (15).
$u_{eq} =$ .... (15)
From equation(7) and (8) the proposed MPPT SM controller design can be demonstrated in (15) as follows:

$$U = \left[\frac{L}{RC} \cdot \frac{d^2 i}{dv2} - \frac{L}{C} \cdot \frac{V_{in}}{V_c} + 1 \right] \text{..................16}$$

The SMC gain (k_a) is an important factor to ensure the SMC stability. Since the compatibility of the PV panel strongly depend on the atmospheric conditions, the SMC gain has been designed to be dependent on the capability of the PV current. The variation of k_a fallows the fourth order polynomial function which is presented below:
$K_{a} =$ .... (17)
Where P1...4 are the polynomial coefficients, which is defined in Table 1, and
is the inductor current. Figure 5 demonstrate SMC adaptive gain varies as the solar irradiance vary from 1000 to 400w/m^2.

$s,\bar{s} < 0$. .... (18)

For the PV system to be stable, k_a should meet the following conditions [21].

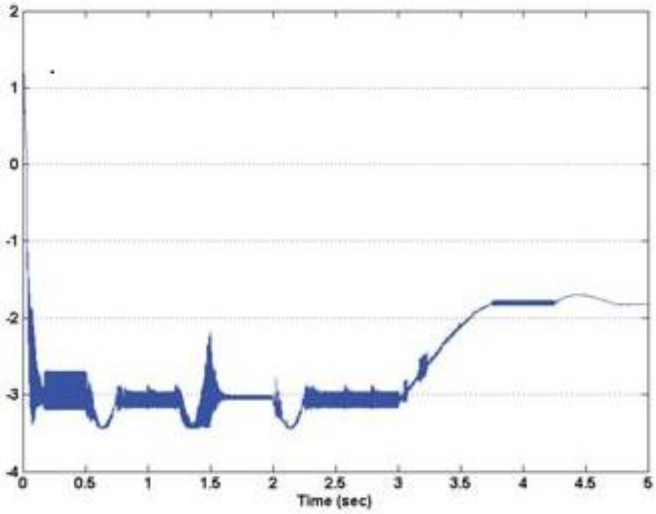

Fig.5: Variation of SMC gain over a range of Solar irradiance

Table 1: PV panel Specification and Polynomial Coefficients.

Description	Symbol	Value	Unit
PV Panel Specification			
Maximum Power	P_{max}	85.2	W
Voltage at MPP	V_{mpp}	17.2	V
Current at MPP	I_{mpp}	4.95	A
Open Circuit Voltage	V_{oc}	22.2	V
Short circuit current	I_{ac}	5.45	A
Solar irradiance	-	1000	w/m^2
Ambient Temperature	T	25	^{0} C
Polynomial Coefficient			
Polynomial Coefficient 1	P_1	0.2629	-
Polynomial Coefficient 2	P_2	-3.049	-
Polynomial Coefficient 3	P_3	12.35	-
Polynomial Coefficient 4	P_4	-20.96	-
Polynomial Coefficient 5	P_5	10.89	-

By analysis of the above equation, second order differentiation terms can be neglected. Since the voltage ratio term is (1-D), equation (19) can be rewritten as below:

By substituting, the values of passive components and the worst case condition, D is zero, the stability and reachability are ensured when 0.787>. Figure (5) checks the SMC stability and is verified that SMC gain satisfy the stability condition during the changing atmospheric conditions.

IV. Simulation Result and Analysis

Fig.1. shows the control diagram of the proposed MPPT SM controller for PV system. Parameters for Measurements are PV voltage and PV current as well as the PV output voltage. For different solar irradiance (from 1000 to 400 W/m^2).

The PV power system is modelled and simulated using MATLAB/SIMULINK and PV specification are shown in Table 1. The model has been simulated

The fig.6. shows the maximum power extracted from the PV system. From the figure it is clear that, the power is maximum with no overshoot. The response time is fast enough and chattering is at its minimum. For all the range of solar irradiance, the operating point of the proposed SM controller lie on the maximum.

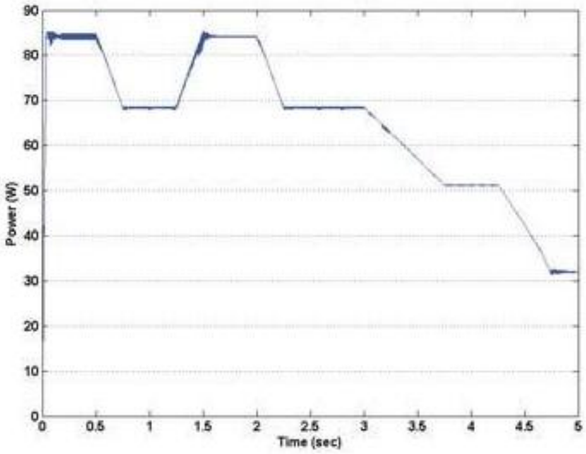

Fig. 6: Output PV power using SMC

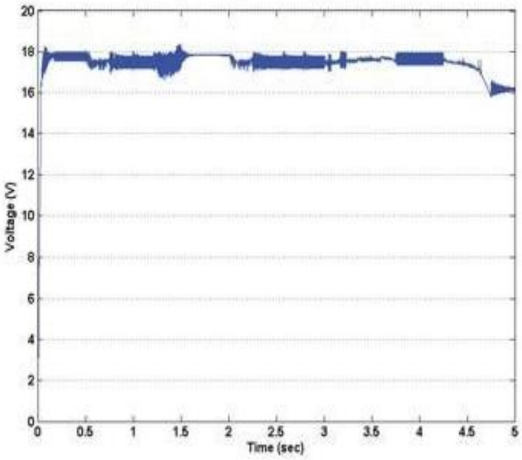

Fig. 7: PV voltage using SMC

Fig.7 shows the PV voltage under different atmospheric condition, perfectly constant operations. This clearly indicates MPP operation as the value of PV voltage matches the PV specification value. Fig 8. Shows the PV current. The effect of atmospheric variation is clearly shown in the PV current. The SM controller forces the system to draw maximum possible current to achieve a MPP operation. The chattering effect is minimum and reduces as the solar radiation decreases.

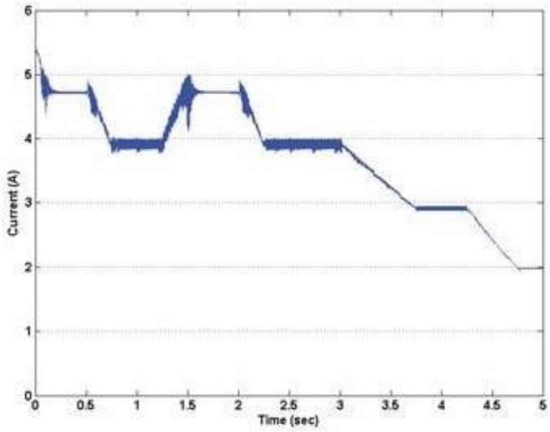

Fig. 8: PV Current using SMC

A Comparison Analysis of the Proposed Controller with Incremental Condition Algorithm.

The fig.9 shows the comparision of Incremental condition Algorithm of MPPT with Sliding mode control controller. It can be seen that operating point of SMC is at the top of the curve of MPP operation even during variation of solar irradiance and also constant voltage operation can be achieved. This justifies that SMC has higher efficiency than incremental conditions

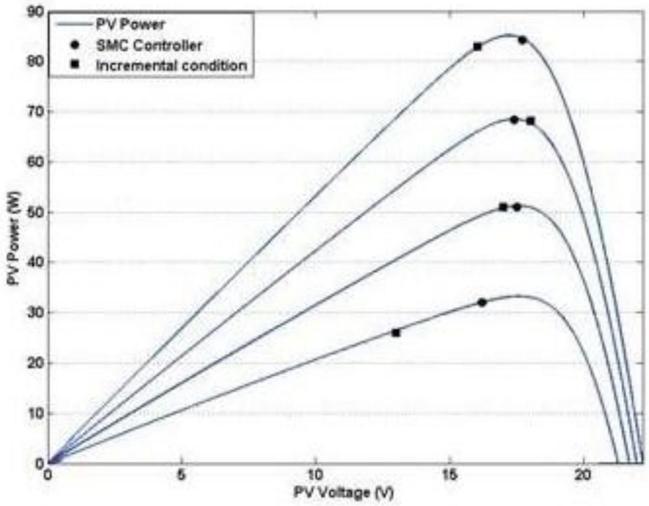

Fig. 9: Operating points during solar irradiance variations

V. CONCLUSION

The PV Panels are connected to a DC load through PWM DC-DC Controller. Using Sliding Mode Control scheme a MPPT Controller has been simulated with the objective to forcethe operating point to be at maximum, during the variation of atmospheric conditions.The Controller atomatically searches for optimal Operating point, independent of atmospheric conditions.From the Simulation results we find there is a perfect achievement of the operating point to the MPP with a satisfactory constant voltage and hence the efficiency of the system is imporved.The Improvementin the behaviour and responseof the PV power system can be attained by using an adaptive gain for an sliding mode controller, as compared to using constant gain.

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