Sliding Mode Control Technique for Single Phase Sub Module Integrated PV System

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Abstract- **The photovoltaic (PV) system that is based on sub module-integrated converters (subMICs) is capable of maximizing solar energy harvest by eradicating power losses due to intra panel mismatch. This paper presents an improved procedure to design a sliding controller for the PV system, which drives the PV voltage to follow a reference provided by an external MPPT algorithm and mitigates the perturbations caused by the irradiance changes and oscillations in the bulk voltage. By considering that the switching surface is the linear combination of the input capacitor current and the PV voltage error, the proposed design exhibits advantages in comparison with existing solutions that rely in the linearization of inner current loop dynamics. However, the simulation of such systems can be very challenging due to the large number of switching-mode power units, nonlinear nature of PV generators, and complication of the coordinating control. This paper provides an effective solution to simulate and control, single-phase grid-tied PV systems that are based on a practical subMICs configuration by sliding mode control. The approach includes the simplified PV cell model and averaged model for power converters, which consider all dynamic interactions among the maximum power point tracking (MPPT).**

Index Terms- **DC/DC power conversion, energy harvesting, photovoltaic power system, sliding mode control, simulation.**

I. INTRODUCTION

Photovoltaic (PV) array is usually composed of solar panels, which are connected in series-parallel combination to meet high input voltage requirement of the centralized power inverter for grid connection. However, significant power loss has been reported due to the unbalanced generation among PV panels, which is primarily caused by partial shading. The dc/dc power optimizer (DCPO), which incorporates a dedicated converter for every panel, has been proposed by researchers to minimize energy loss during mismatch conditions. Each DCPO performs independent maximum power point tracking (MPPT) to mitigate the mismatch effect among the series-connected solar panels. This configuration successfully eliminates the power loss resulting from the interpanel mismatch but cannot mitigate the loss caused by intrapanel mismatch. To increase solar energy harvest by eradicating intrapanel mismatch, submodule integrated converters (subMICs) have been developed. Both DCPO and subMIC are similarly designed for cascaded structures where converter outputs are connected in series. Modeling and simulation of subMIC-based systems are necessary to analyze the impact of partial shading, prove new control strategies, optimize system configurations, and analyze system dynamics, etc. Furthermore, the evaluation of the system performance under uniform shading, partial shading, and non shading conditions can also be carried out using different modeling approaches.

Switching models of converters and equivalent circuits of PV units are commonly utilized to simulate centralized PV systems. The same technique is not suitable for the simulation of sub MIC-based PV systems using a standard desktop computer because of large numbers of subMICs and PV sub modules in the system configuration, and the high switching frequencies of the dc/dc converters. High switching frequencies aim to reduce the overall sub MIC size to utilize small size components, e.g., capacitors and inductors that can fit into the junction box of PV panels.

The PV module is the interface which converts light into electricity. Modeling this device, necessarily requires taking weather data (irradiance and temperature) as input variables. The output can be current, voltage, power or other. However, trace the characteristics I(V) or P(V) needs of these three variables. Any change in the entries immediately implies changes in outputs. That is why, it is important to use an accurate model for the PV module. This paper presents a detailed modeling of the effect of irradiance and temperature on the parameters of the PV module. The chosen model is the single diode model with both series and parallel resistors for greater accuracy. The detailed modeling is then simulated step by step using MATLAB/Simulink software due to its frequent use and its effectiveness. All the aspects that show impact on the power output are considered, which include double frequency ripple, temperature variations, uniform irradiance changes, uneven PV temperature distribution, and partial shading scenarios. Additionally, the model accounts for the effect of changes in grid voltage and frequency and shows their influence on the dc-link and inverter input current. Furthermore, the discrete dc-link voltage control and PV submodule voltage regulation is applied, which emulates the actual digital control using microcontrollers in a real-world system.

II. MODELLING OF PV CELL

Among a variety of renewable energy sources, solar energy is predicted to become the largest contributors to world energy for its clean and no supply limitations characteristic. Over the past decade, PV technology has shown the potential by robust and continuous growth even during times of financial crisis.

The key technology of a PV system includes PV cell modeling, maximum power point tracking (MPPT) algorithm, DC/DC converter and grid-connected DC/AC inverter. Photovoltaic (PV) cell is a semiconductor device that absorbs and converts the energy of light into electricity by photovoltaic effect. Figure shows the equivalent circuit of PV Cell.

By applying Kirchhoff law, current will be obtained by the equation:

$$I = I_{\text{ph}} - I_{\text{d}} - I_{\text{p}} \quad (1)$$

I_P, is the current leak in parallel resistor. According to the equation, the output current of a module containing Ns cells in series will be:

$$I = I_{\text{ph}} - I_0\left[\exp\left(\frac{V + I.R_S}{a}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (2)$$

$$a = \frac{N_S \cdot A \cdot k \cdot T_C}{q} = N_S \cdot A \cdot V_T \quad (3)$$

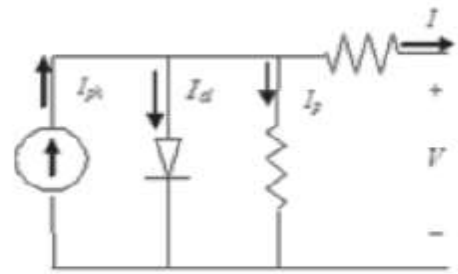

Fig.1 Equivalent circuit of PV Cell

A. Determination of the parameters:

The number of parameters varies depending on the chosen model and on the assumptions adopted by the searchers. It is considered that Iph, Is, Rs, Rp and the factor ideality are five parameters that depend on the incident solar radiation and the cell temperature.

In this work the four parameters that have to be evaluated are also Iph, Is, RS,RP.

- *Determination of Ip:*

$$I_{ph} = \{[(T_{op} - T_{ref}).K] + I_{sc}\}.I_{rr} \quad (4)$$

Where, Irr=Solar irradiance(W/m^2), Isc=Short circuit current, K=Temperature coefficient of short circuit current, Tref=Cell temp at STC=25+273=298K, Top=Operating temp.

- *Determination of Is:*

$$I_s = I_{rs}.\frac{T_{op}}{T_{ref}}^3 .e^{\frac{1}{Top}-\frac{1}{Tref}\frac{q.Eg}{K.n}} \quad (5)$$

Where, Irs=Reverse saturation current at operating temperature, q=Charge, Eg=Material band gap energy=1.12eV for Si.

III. SUBMODULE INTEGRATED CONVERTERS

Under the small-scale mismatch conditions, the subMIC based PV system is superior to the systems of DCPO and centralized configuration in terms of solar energy harvesting. It is shown that the subMICs offer an effective solution to maximize the utilization of PV power by employing MPPT on the submodule level. The submodule is a section of a PV panel consisting of 15 to 24 PV cells in series connection.Advantage of subMICs systems lies in the utilization of distributed MPPT to the submodule level to eradicate mismatch among submodules. Therefore, the subMICs-based system shows higher energy yield in comparison with the centralized inverter, DCPO, and micro inverter configurations. In a quantitative comparison of PV energy harvesting architectures of string, power optimizer, micro inverter, and subMICs is presented. The 30-year prediction of solar energy harvest showed that the subMIC-based system produces more energy than other system approaches with the consideration of various types of installations including ground-mounted power plant, rooftop installation, facade PV, and electric vehicles. 90% of the mismatch loss can be recovered by applying a unified control approach, which controls three sub-MICs connected to each PV panel. A subMIC product is developed, which reports 20% more energy harvesting in comparison with the DCPO under specific shading conditions. The study compares the performance of the subMIC solution with centralized PV system and reports 6.9%–11.1% more annual energy output. Furthermore, the subMIC-based system have been proved to be low cost and high efficiency. In subMIC architecture, the inputs of dc/dc converters are connected in parallel to submodules to perform MPPT, whereas the outputs are connected in series. The series connection of subMICs delivers a voltage stack to achieve the required dc-link voltage, which is the input of a centralized grid-tied inverter. The voltage stack provides the flexibility to operate each sub-MIC at relatively low conversion ratio, which results in higher efficiencies compared to the solution of micro inverters. A typical micro inverter is required to boost the voltage from the PV module level of 22–45 Vdc to the grid level of 220 Vrms or 240 Vrms in ac.

IV. MAXIMUM POWER POINT ALGORITHM

To improve the efficiency of the solar panel MPPT is used. According to maximum power point theorem, output power of any circuit can be maximize by adjusting source impedance equal to the load impedance, so the MPPT algorithm is equivalent to the problem of impedance matching. In present work, the Boost Converter is used as impedance matching device between input and output by changing the duty cycle of the converter circuit. Output voltage of the converter is depend on the duty cycle, so MPPT is used to calculate the duty cycle for obtain the maximum output voltage because if output voltage increases than power also increases. In this Perturb and Observe (P&O) and constant duty cycle techniques are used, because these require less hardware complexity and low-cost implementations.

A. Perturb & Observe MPPT Algorithm :

A photovoltaic (PV) array under uniform irradiance exhibits a current-voltage characteristic with a unique point, called the maximum power point (MPP), where the array produces maximum output power.

The P&O MPPT algorithm is mostly used, due to its ease of implementation. It is based on the following criterion: if the operating voltage of the PV array is perturbed in a given direction and if the power drawn from the PV array increases, this means that the operating point has moved toward the MPP and, therefore, the operating voltage must be further perturbed in the same direction. Otherwise, if the power drawn from the PV array decreases, the operating point has moved away from the MPP and, therefore, the direction of the operating voltage perturbation must be reversed.

It is the simplest method of MPPT to implement. In this method only voltage is sensed, so it is easy to implement. In this method power output of system is checked by varying the supplied voltage. If on increasing the voltage, power is also increases then further ‘δ’ is increased otherwise start decreasing the ‘δ'. Similarly, while decreasing voltage if power increases the duty cycle is decreased. These steps continue till maximum power point is reached. The corresponding voltage at which MPP is reached is known as reference point (Vref).

V. DC/DC CONVERTER

A DC/DC converter serves the purpose of transferring maximum power from the solar PV cell to the load. A DC/DC converter acts as an interface between the load and the PV cell. By changing the duty cycle, the load impedance is varied and matched at the point of the peak power with the source, so as to transfer the maximum power. There are Four basic topologies for DC/DC converter: Buck, Boost, Buck-Boost and Cuk.

A. Reason for Choosing Boost Converter:

Chosen the classical boost converter to implement the MPPT algorithm for the following reasons.
1) For Boost Converter, the output voltage is always higher than the input PV cell voltage, which is convenient for the PV cell to be connected to the grid later.
2) The topology for Boost Converter is simple, easy to implement, and has high efficiency.
3) The Boost Converter is easy to be controlled to minimize fluctuation and increase tracing accuracy.

B. Operating Principle of Boost Converter:

Below Fig shows the topology of Boost converter. For this converter, power flow is controlled by means of the on/off duty cycle of the switching transistor. When the switch is On for t_{on} seconds, current flows through the inductor in clockwise, and energy Vi.Il. t_{on} is stored in the inductor. When the switch is Off for t_{off} seconds, current will be reduced for increasing impedance. The only path of the inductor current is through diode D to the capacitor C and load R. The polarity of inductor will change. And the energy accumulated in the inductor during the On-State will be released, (Vc-Vi)Il.t_{off}.

Vi.Il.t_{on}=(Vc-Vi)Il.t_{off}

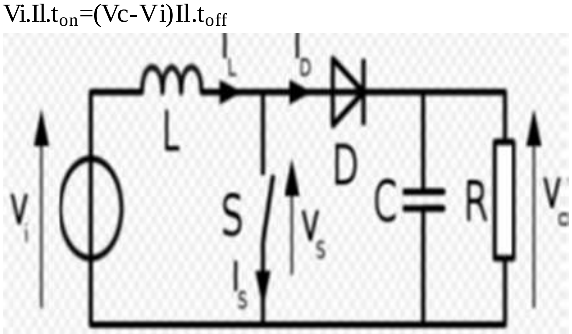

Fig.2 Topology of Boost Converter

VII. SLIDING MODE CONTROLLER

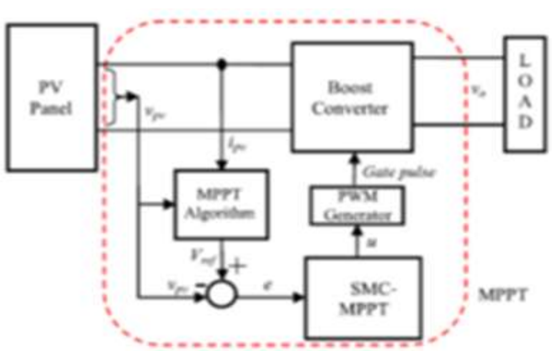

Fig.3 Block Diagram of PV System with SMC

An implementation of a maximum power point tracker, based in reaching a reference open circuit voltage, using a sliding mode controller obtained to control the duty cycle of a DC-DC converter in order to force the PV module to operate at its maximum power point, for a given temperature and irradiance, to improve the utilization of the produced energy when connected to a load. For this case the load it's a battery and a resistance. This SMC employs one reaching phase and another sliding phase. The sliding phase consists of higher switching frequency known as chattering. Though chattering is responsible for the robustness of this technique but it is objectionable because of switching losses and electromagnetic interference. Block diagram of simple PV system with SMC-MPPT

The MPPT used here is the open circuit voltage MPPT, this method uses Voc to calculate Vmp.

$$V_{oc} = N_s V_t \ln\left(\frac{I_{pv}+I_0}{I_0}\right) \tag{6}$$

When the system obtains the Voc value , Vmp is calculated by :

$$V_{mp} = k * V_{oc} \tag{7}$$

Where k is the material coefficient of PV module which depends on structure and material of the PV module. The k value is between 0.70 to 0.80. It is necessary to update Voc occasionally to compensate for any temperature change.

The basic idea of the SMC is attracts the state of the system in a selected area of the state space, which is known as the sliding surface and in conceiving the control law in a finished time and to maintain the system towards this area.

$$x^0 = f(x,t) + g(x,t)u \tag{8}$$

Let $S\ x$, be the sliding surface and its derivative is given by:

$$S^o = \frac{ds(x,t)}{dt} = \frac{1}{dt}\left(\frac{\partial s}{\partial x}dx + \frac{\partial s}{\partial t}dt\right) = \frac{\partial s}{\partial x}x^o + \frac{\partial s}{\partial t} \tag{9}$$

G is the gradient of S, then:

$$S^o = Gf(x,t) + Gg(x,t)u + \frac{\partial s}{\partial t} \tag{10}$$

The sliding mode control composes of the terms including the discontinuous control in function of the sign of the sliding surface un, an equivalent control ueq characterizing the dynamic of the system on the sliding surface.

$$u = u_{eq} + u_n \quad (11)$$

un corresponds to the non-linear component and is determined to ensure the attractiveness of the control variable to the sliding surface and satisfies the convergence condition

$$S(x).S^o(x) < 0$$

$$u_n = k_{eq} S(x) \quad (12)$$

The sliding mode control function is to track the maximum power point by changing the duty cycle of the boost converter.

$$\frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv} = 0$$

$$S(x) = \frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} \quad (13)$$

$$S(x) = 0 \; and \; \frac{ds(x)}{dt} = 0$$

$$u_{eq} = 1 - \frac{V_{pv}}{V_0} \quad (14)$$

That is by taking the values of load voltage and PV panel voltage, the duty ratio for the boost converter can be estimated. Hence,

$$u = u_{eq} + k_{eq} * S \quad (15)$$

The input to the controller is the change in PV voltage and the reference voltage,(e) output of the sliding mode control will be change in the duty cycle

VI. SIMULATION& RESULTS

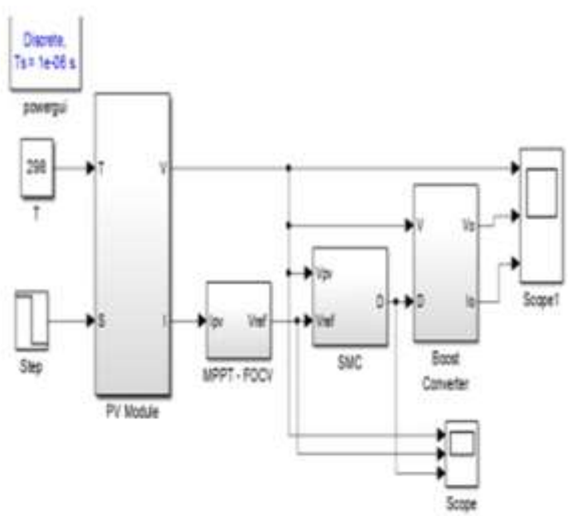

Fig.4 Modeling and Simulation of PV Cell in MATLAB/Simulink

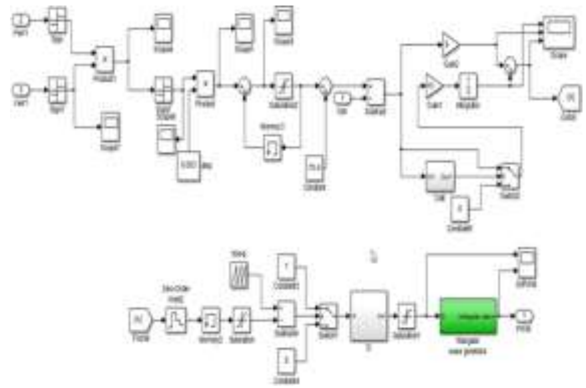

Fig.5 Simulation Diagram of SMC-MPPT

The simulation result is shown in Figures. Figure 6 shows the I-V characteristic curves of the PV cell. Figure 7 shows the P-V characteristic curves. The model curves exactly match with the experimental data at three remarkable points: short-circuit, open-circuit, and maximum power point.

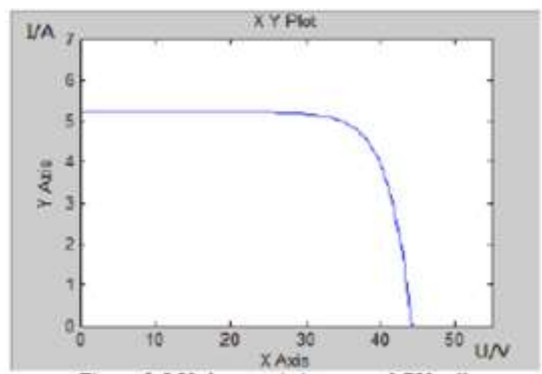

Fig.6 I-V Characteristic Curve of PV Cell

It can be seen that when the output voltage is less than a threshold value, the change of output current is very small with the changing of voltage. PV cell acts like a constant current source; when the output voltage exceeds a threshold value, the current declines sharply with increasing voltage. PV cell acts like a constant voltage source.

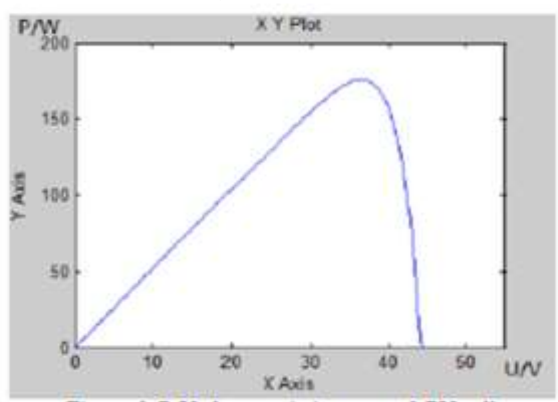

Fig.7 P-V Characteristic Curve of PV Cell

The I(V) characteristics are presented in by varying irradiance from 200 W/m2 to 1000 W/m2 and taking The STC temperature.

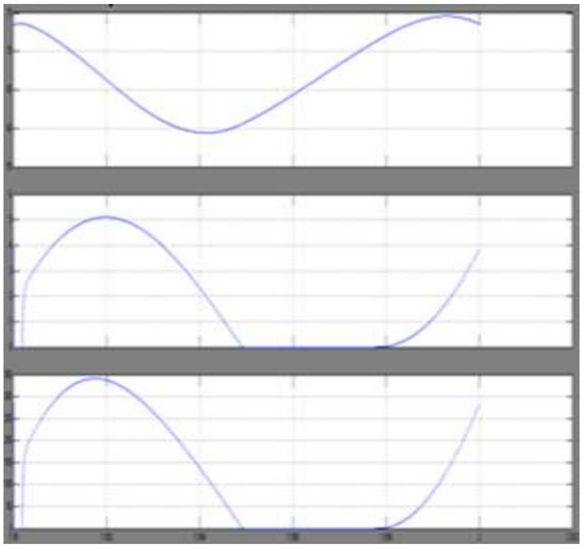

Fig.8 characteristic curves of boost V/I/P

Fig 8 shows output waveforms of voltage, current and power after using sliding mode control technique for boost converter.

VII. CONCLUSION

This paper has proposed an improved procedure for designing the sliding mode controller of a boost converter in a grid connected PV system. Its PV voltage tracked the reference provided by an external MPPT with a specified settling time and no overshoot while being insensitive to changes in environmental conditions, such as solar irradiation or PV module temperature, and the capacitor voltage linking the boost converter. An efficient and fast simulation technique is presented to simulate subMIC-based grid-tied PV systems, which is a difficult problem due to the significant number of PV submodules and subMICs. The simulation model is developed using the averaging technique of power converters in combination with the simplified PV model.

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