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Photovoltaic Energy Transformation Systems with Controlling of Variable Structure

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Abstract (Size 10 & bold &Italic)— This paper proposes a novel power electronics controlling Variable Structure architecture for solar energy conversion systems. To enhance the quantity of energy generated by solar panels, the perturb-and-observe maximum power point tracking approach is applied. The purposed first and higher-order controlling of Variable Structure techniques are provided to handle the irradiance and load fluctuation issue, as well as to improve the power conversion efficiency. Compared to the first-order approach, the higher-order sliding mode technique greatly minimises the chattering effect in the buck-boost converter. The output of the DC-DC converter is supplied into a voltage-oriented control based space-vector pulse-width-modulated inverter for three-phase AC power generation in a freestanding system. The suggested power electronics control strategy for solar energy systems has been demonstrated in computer simulations to be effective and resilient.

Keywords **(Size 10 & Bold) —** *Put your keywords here, keywords are separated by comma.*

I. INTRODUCTION (SIZE 10 & BOLD)

Photovoltaic systems employ semiconductor material features to transform solar energy into electrical energy [1]. There are three different forms of silicon. Amorphous material has a cell efficiency of around 13%, mono-crystalline has a cell efficiency of 17-23%, and polycrystalline has a cell efficiency of 14-17%. Solar energy has several advantages for consumers. For example, solar panels have warranties ranging from 25 to 35 years depending on the manufacturer, and solar systems are far cheaper than wind generating for domestic applications. There are no moving components, pollutants, or noise in this environment. As a result, photovoltaic energy is regarded as one of the green energy alternatives.

Photovoltaic panels on a utility scale provide active power. This contribution boosts capacity, allowing more loads to be connected to the grid. When solar plants are integrated, They reduce the demand for conventional energy sources.. This is also known as flexible energy generation or dispersed generating, and it produces fewer carbon emissions [1].

The primary issues for inverters are switching losses and harmonics [6] [7]. Because of these flaws, the output waveform is warped. State-vector pulse width modulation design is a common inverter control method. Losses and harmonics are minimised, while efficiency is increased. As a result, SVPWM inverters are used in stand-alone and grid-tied applications. This paper proposes a two-level space-vector pulse width modulated inverter design to reduce harmonics and distortion.

II. MAXIMUM POWER POINT TRACKING ALGORITHMS

There are a number of control strategies that may be used to ensure that maximum power is delivered from solar cells to the load. To change the voltage level and function at the highest power point at any given time, a DC-DC converter is required. In Fig. 3.1, you can see a simple system structure. Maximum power point tracking algorithms are used to find and maintain the optimal point in solar DC to DC converters. Even if there is a change in the system, thevenin impedance of solar panels and associated loads match, thus losses are avoided by applying MPPT techniques.

MPPT control approaches provide accuracy, consistency, and precision throughout operation, allowing the system to adapt quickly to any unexpected changes. For power maximisation, more responsive algorithms are desirable since the sooner the controller responds, the more power may be provided. Fractional open-circuit voltage technique, fractional short-circuit current method, incremental conductance method (ICM), and perturb and observe (P&O) are some of the most common methods.

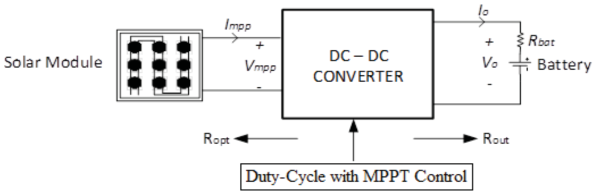

Fig 1: Using DC-DC converters for MPPT control

A. *Fractional Open-Circuit Voltage Method (FOC)*

Fractional open-circuit MPPT method is one of the simplest algorithm to track the optimum operating conditions. System control is performed based on fractional relationship between V_{mpp} and V_{oc} as

$$k = \frac{V_{mpp}}{V_{oc}} \tag{1}$$

where k represents proportionality constant [14] [15]. The ratio is usually measured around 0.7 and 0.8, according to [15]. For instance, the solar panel that was designed in chapter two has k ratio of 0.7883.

$$k = \frac{V_{mpp}}{V_{oc}} = \frac{30.9\ V}{39.2\ V} = 0.7883$$

Once the k constant is measured, the controller measures both panel output voltage and panel open-circuit voltage periodically. The system decides if the panel voltage needs to be increased or decreased to equalize the module voltage to V_{mpp}.

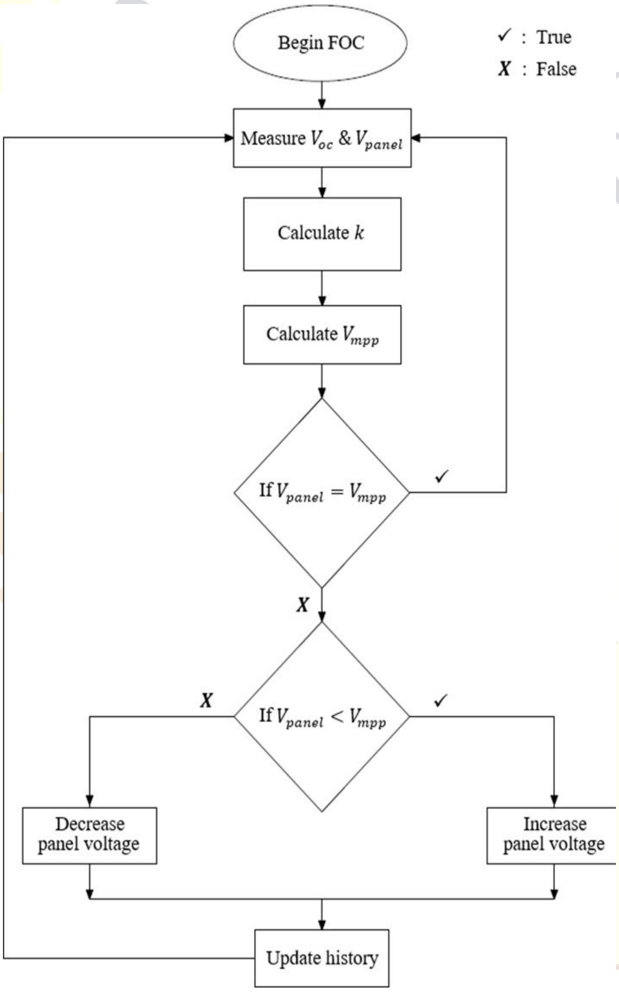

Figure 2: Fractional open-circuit voltage (FOC) method flow-chart

B. *Perturb and Observe Method(P&O)*

Another prominent MPPT approach is the Perturb and Observe algorithm. This technique is also known as the "slope climbing technique." Because the P&O focuses on impedance matching rather than conductance matching, it might be regarded a modified form of the ICM.

The converter controller unit calculates the power once the current and voltage from the panel are measured. The power that results is compared to the prior value. The duty cycle is set up to regulate the switching element, and it may be changed based on where the power is on the P-V curve. For example, if the power point is on the left-hand side of the MPP and power is flowing higher on the graph, both power and voltage changes become positive. In this scenario, the duty cycle should be changed to boost panel voltage to attain the panel's maximum capable power rating. If panel voltage is increased too much, and if Pmpp point is passed, module voltage needs to be decreased by altering the duty cycle to obtain the peak power point again. Once the peak power region is achieved, the duty cycle ripples with a small step size to maintain that region. The following equations are used to determine if change in power and voltage is positive or negative [13] [18].

$$\Delta P = P_k - P_{k-1} \tag{2}$$

$$\Delta V = V_k - V_{k-1} \tag{3}$$

$$\Delta P \Delta V < 0$$

$$\Delta P \Delta V > 0$$

Based on the equations and notations above, a P&O controlled converter can easily be implemented. This method improves accuracy and efficiency of the system with low system cost [15].

III. DC-DC CONVERTERS

DC to DC converters are utilised in a variety of applications, including DC motor control, UPS, battery controllers and chargers, DC voltage regulators, and inverter feeders, where the voltage rating must be converted from one level to another. DC power is generated via solar panels. Panel output ratings can be increased or decreased to a suitable level. When a solar array is linked to the utility grid, the panel output voltage is increased to make the system more cost-effective. Otherwise, additional solar panels are required to enhance voltage, the overall cost of the PV system rises significantly, and utility corporations profit for a longer length of time than they should. Buck or buck-boost converters are ideal for operation when panels are serving low-power applications like as battery chargers.

Different combinations of active and passive power components with an inductor are used in inductive and non-isolated converters. When the duty cycle is high, the inductor is turned on. The inductor feeds the load when its voltage is low. When the inductor is activated, the capacitor serves as a voltage source to maintain the output voltage constant. The following converter types have a diode that is only active in low-mode. Period-duty cycle connection is represented by equations (4)-(6).

$$T_{sw} = T_{on} + T_{off} \quad (4)$$

$$T_{on} = DT_{sw} \quad (5)$$

$$T_{off} = (1-D)T_{sw} \quad (6)$$

Equations (7)-(9) represent diode and inductor current-duty cycle relationship [21].

$$I_L = I_T + I_D \quad (7)$$

$$I_T = DI_L \quad (8)$$

$$I_D = (1-D)I_L \quad (9)$$

Where $I_L, I_T, I_D, and\ T_{sw}$ represent inductor, transistor, diode currents, and switching period respectively. T_{on} denotes the period when switching device is on, and Toff denotes the switching element is off. D stands for duty cycle.

Table I

BOOST CONVERTER DESIGN PARAMETERS AND PHYSICAL SIGNFICANCES

$\%\Delta I_L$ max	5%	Desired percent ripple on input current
$\%\Delta V_C$ max	5%	Desired percent ripple on output voltage
L	2.2 mH	Inductor rating
C	67 μF	Capacitor rating
R	11.5 Ω	Load resistance
D	0.728	Duty cycle ratio

IV. SLIDING-MODE CONTROL

The Nonlinear properties are shown by DC-DC converters [22]. Traditional PID controllers are commonly used in real high power converter systems for simple and responsive design goals, based on the Jacobian linearizion of the nonlinear system, which generally offers poor performance with inadequate conversion efficiencies. To obtain improved performance under high-level system nonlinearity, time-varying irradiation, and load fluctuations circumstances, a more robust nonlinear control approach is required [5] [23] [24].

The sliding-mode control approach provides applications with resilience and stability. Because the SMC is very robust to system changes, it utilises less information. This benefit reduces the number of variables and simplifies the computation [2]. Because of these characteristics, sliding-mode control is an extensively utilised control method.

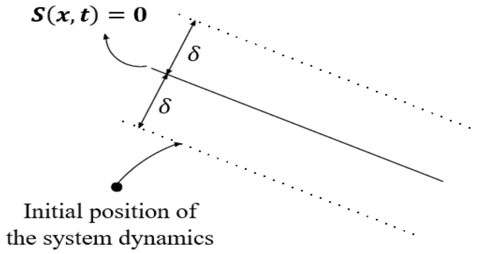

Figure 3: Reaching the sliding surface

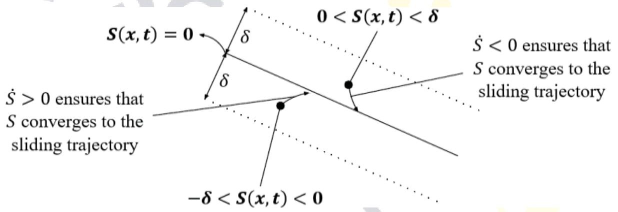

Figure 4: Existing the sliding surface

The stability condition must be met to ensure that the sliding surface always directs the trajectory toward a stable equilibrium. It is obtained by checking the stability of the system in the steady-state region.

V. DESIGN AND SIMULATION STUDIES

The analyses for solar power generation and conversion systems were discussed in detail. The purpose of this simulation can be expressed in stages: generating 100 kW solar power, charging batteries, boosting battery voltage to a desired voltage level, converting DC to AC, and powering a three-phase load after filtering.

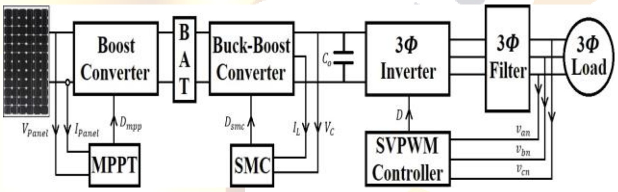

Figure 5: Overall system block diagram

To optimise the available solar power generation, the perturb-and-observe maximum power point tracking technique is used. For buck-boost converter control, the purposed first and high-order sliding-mode control techniques are used, and for AC power production, a voltage-oriented control based space-vector pulse width modulated high power inverter is constructed. The total PV energy conversion system block diagram is shown in Fig. 5. In the sections that follow, each block is designed, and entire system simulation results are shown along with remarks.

$$V_{panel} = (\#\ of\ panels\ in\ series)\ V_{mpp} \quad (10)$$

$$V_{panel} = (17\ panels)\ 30.9\ V = 525.3\ V$$

$$I_{panel} = (\#\ of\ panels\ in\ parallel)\ I_{mpp} \quad (11) \qquad P_{panel} = V_{mpp}\, I_{mpp} \quad (12)$$

$$I_{panel} = (22\ panels)\ 8.81\ A = 193.8\ A \qquad P_{panel} = 525.3\ V.\ 8.81\ A = 101.8\ kW$$

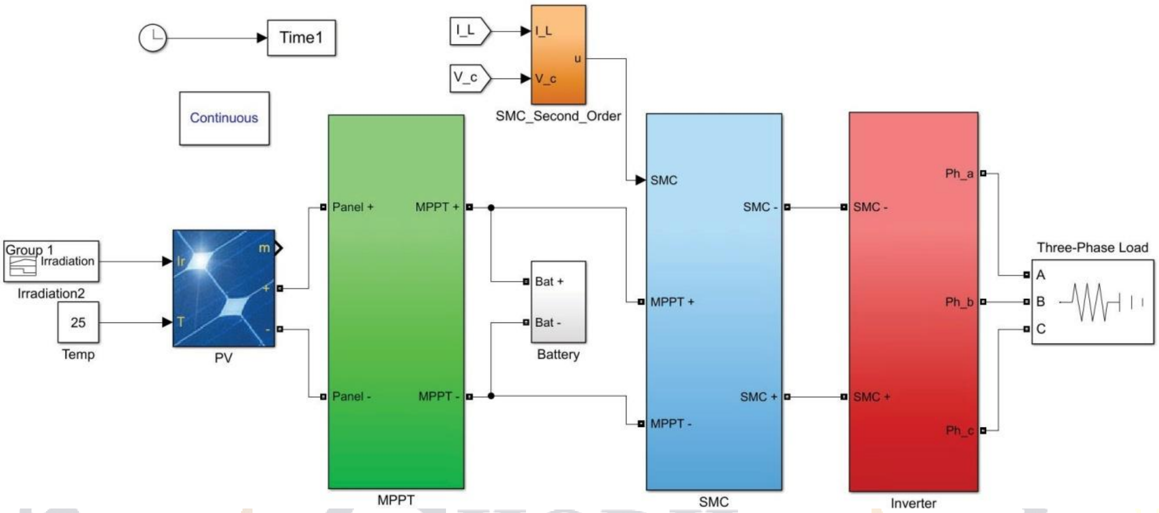

Figure 6: Overall system design controlled by second-order sliding-mode controller

Initially, the panel voltage had been observed as 666.4 V since the array was open circuited. During the operation, the system reached to its maximum ratings for both current and voltage under changing and constant irradiation. Thus, the I-V and P-V curve lines always followed the optimum point for changing irradiation case, but stopped at the MPP at constant 1000 W/m2. When no weather or load variations are observed, the MPPT controller operated at the same duty cycle.

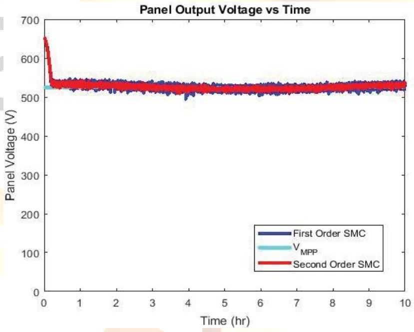

Figure 7: PV array output voltage under changing irradiation

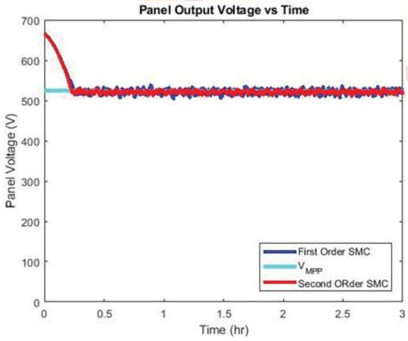

Figure 8: PV array output voltage at 1000 W/m^2

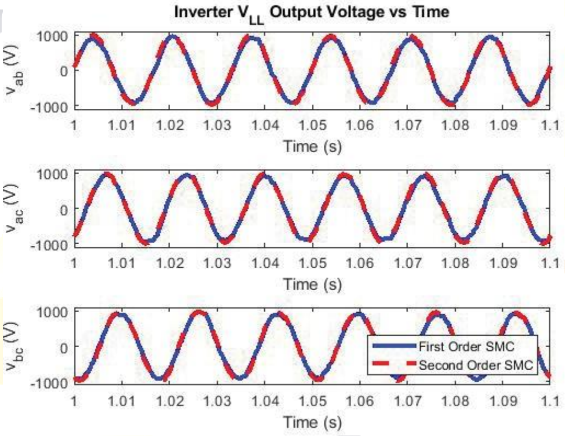

Figure 9: SVPWM inverter V$_{LL}$ output voltage under changing irradiation

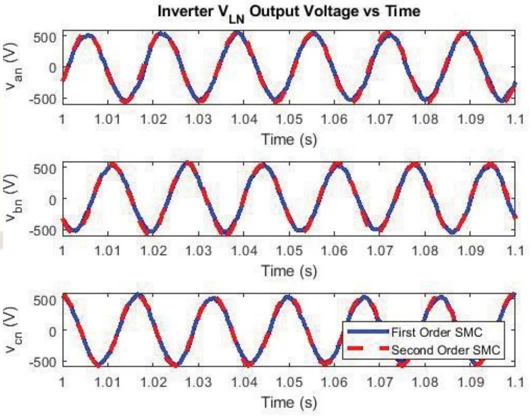

Figure 10: SVPWM inverter V$_{LN}$ output voltage under changing irradiation

VI. CONCLUSIONS

A novel DC-DC converter controlling of Variable Structure approach is proposed for solar energy conversion systems. The perturb and observe method is utilized to achieve the maximum power point tracking of the PV panels. The first and higher-order controlling of Variable Structure techniques are proposed to robustly and effectively control the DC-DC converters, under sunlight irradiance and load perturbations. The DC output is directly connected to a SVPWM based high power inverter feeding microgrid or isolated three-phase AC loads. It has been shown that the proposed higher-order sliding control improves the overall converter efficiency and significantly reduced the chattering phenomenon. The photovoltaic energy conversion system has been simulated in MATLAB/Simulink and results have been provided and analyzed. The proposed method can be a powerful alternative power electronics control approach to the existing solar energy conversion systems.

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