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MPPT CONTROL METHOD OF PHOTOVOLTAIC SYSTEM UNDER COMPLEX LIGHTING CONDITIONS

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ABSTRACT

Due to the depletion of fossil fuels and the effects of global warming, the globe is shifting toward renewable energy sources. The sun is the most potent source of energy among these renewable ones. A popular renewable energy source is solar energy. Due to the non-linear behavior of the solar photovoltaic PV system under actual environmental settings, the output power changes for dynamic environmental conditions, reducing the systems efficiency. A control strategy is necessary for maximum power extraction under all circumstances in order to obtain the most power. The maximum power has been extracted using a variety of maximum power point tracking MPPT methods. Sliding mode control SMC, one of these MPPT strategies, is a popular method for non-linear systems to manage uncertainty. This thesis focuses on comparing and analyzing SMC methods for MPPT. Moreover, we sought to deal with the behavior of a PV system using a non-linear higher-order sliding mode control HOSMC approach known as the super-twisting algorithm STA.

Keywords: Photovoltaic (PV), Maximum Power Point Tracking (MPPT), Partial Shading Conditions.

I. INTRODUCTION

Background

The need for renewable energy sources has grown as a result of the fuel crisis and global warming. Oil, coal, and natural gas are conventional energy sources, but they are insufficient to provide the massive global energy demand. Therefore, natural resources such as sunshine, rain, tides, wind, biomass, and geothermal heat are examples of renewable energy sources. The fact that renewable energy sources are cheaper, needless upkeep, and have a longer lifespan is one of the fundamental justifications for using them. A promising source of energy is solar energy [1]. It was British astronomer John Herschel who first proposed using solar energy [2]. The solar radiation that is incident is transformed into electrical energy.

Photovoltaic System

According to the European Industry Association EPIA, by 2030, the quantity of power produced by solar PV technology might reach up to 800 GW. Due to a number of significant benefits, solar PV technology has experienced exponential growth [7]. The sun, which is a free energy source, is used in this technique. As a result, it is seen as sustainable and infinite. The PV system has a long lifespan Sunlight is directly converted into power. The technique does not produce carbon dioxide, there is no pollution problem. No mechanical moving components are used, therefore there is no noise produced by PV technology, which can provide electricity in the range of microwatts to megawatts. PV systems are made up of PV cells and other components that employ the direct conversion of light energy into electricity [6]. Semiconductor components that are PN junction devices make up the PV cell. These semiconductor materials include silicon that is mono crystalline, polycrystalline, thin film, amorphous, sphere-shaped, and concentrated [10].

Maximum Power Point Tracking (MPPT)

As we previously noted, the PV systems key issues include non-linear output and low energy efficiency. PV modules have a conversion efficiency of 10 to 15. To ensure that the connected load receives the greatest amount of power from the PV source under all climatic circumstances, MPPT controllers are utilized to regulate the functioning of the power conditioning unit. The development of an effective MPPT technology and the use of the appropriate DC-DC converter is crucial for the successful and economical functioning of PV systems [11].

Types of PV System

PV systems are often categorized according to their installation capacity, component requirements, area preferences, and connections to various loads. Stand-alone and grid-connected PV systems are the two primary varieties. An autonomous system produces power without using the grid. This technique is better suited for the most isolated areas without grid access or alternative energy source. In this distant area, it makes up the bulk of PV installations. Due to inherent limitations such as a low capacity factor, higher battery prices, and a restricted capacity for energy storage, stand-alone PV systems waste the excess energy produced [11] [12].

Problem Statement

The nonlinear characteristics curve of the PV system makes it extremely difficult to extract the systems full potential. The operating external circumstances have an impact on the IV and PV characteristics curves of PV cells. A specific place on a curve where we can obtain the most power is known as the maximum power point MPP. Depending on the surroundings, that point changes. Therefore, having a PV system running at the MPP under all operational circumstances is both a necessary and difficult undertaking. If not, the PV systems performance starts to decline.

II. LITERATURE REVIEW

PV System

PV systems exhibit non-linearity in their power production, poor energy efficiency, and high PV module costs. Earlier, the PV module was highly expensive, but due to mass manufacturing and advancements in technology, it is now a practical and inexpensive technology for the majority of users. However, the installation costs are still considerable, and the conversion efficiency is lower. Only 10-15 of PV modules are efficient in converting power. To guarantee the greatest amount of power is transferred from a PV source to a linked load, MPPT schemes are utilized to regulate the operation of the power conditioning unit [14].

MPPT Techniques

Researchers have created a large variety of MPPT approaches, and these techniques are categorized according to how simple they are to use, how efficient they are in terms of calculation time, tracking and convergence speed, cost, and the number of sensors [15]. Conventional MPPT control methods MPPT controls for intelligence MPPT optimization strategies The literature contains algorithms for linearization-based MPPT, DC-link capacitor droop control-based MPPT, online-MPP search, incremental conductance, perturb and observe, hill climbing, constant voltage, ripple correlation control, look-up table method, and fractional short circuit current for classical MPPT [16] [17]. The less sophisticated algorithms of the classical approaches make them simple to implement. Additionally, they are regarded as the most efficient for uniform irradiation conditions as the PV system will only produce one single global maximum power point under these circumstances. The traditional algorithms, however, exhibit quick oscillations and swings around the MPP, and these oscillations cause power loss. Artificial neural networks, sliding mode controls, fuzzy logic controls, the Gauss-Newton method, and the Fibonacci series are a few examples of intelligence-based MPPT systems [16][18]. The intelligent-based techniques are extremely accurately created for the requirements of a dynamic environment. They feature quick tracking speeds and great tracking efficiency. However, these methods need a complicated control circuit and a lot of data processing for system training. The innovative method, fuzzy logic control, requires no prior system knowledge for MPPT implementations.

Sliding Mode Control (SMC)

The initial research on SMC development for the DC-DC converter was done in 1983 and 1985. The first group gave an example of how SMC may be used in a DC-DC converter. But just the buck converter was the subject of the effort. Later, in 1985, the full SMC descriptions for use with all fundamental 2nd-order DC-DC converter topologies were given. Additionally, they illustrated the idea of linking duty ratio control techniques of the pulse width modulation PWM technology to analogous SMC control methods for maintaining constant frequency [28].

Higher Order SMC

As a result, research on higher-order SMC, such as terminal SMC TSMC, super-twisting algorithm STA SMC, and artificial intelligence algorithm SMC, is also available in the literature. Higher-order SMC MPPT techniques are more expensive to implement than regular SMC techniques because they need extremely quick processing resources to complete sophisticated computations [36].

State of the Art

A Fast Current-Based MPPT Technique Employing Sliding Mode Control is the subject of [37]. The goal is to put the unique MPPT technique into practice in order to maximize the power collected by PV systems. An SMC method has been designed. The goal of the work is to develop a dual technique based on an inner current loop and an outer voltage loop to benefit from the inner current loops fast current tracking and the outer voltage loops advantage of the PV systems voltages logarithmic dependence on solar irradiation. The experimental findings are displayed to verify the method. This study displays theoretical analysis and simulations. The suggested design has been compared to implementations of the traditional PID voltage feedback with the pulse width modulator. The proposed design is based on the PI voltage feedback that is interfaced with SMC PWM. Both systems are constructed with a crossover frequency of 2 kHz. The outcome demonstrates that even with simpler voltage correction, it results in a superior dynamic response in the 50 irradiance changes [39] [40].

III. SYSTEM MODELING, SIMULATION

Block Diagram

Below is a block schematic of a PV system that is linked to the grid. The suns energy powers PV panels. A DC-DC buck-boost converter is provided the PV arrays output. To obtain the most power possible for each input, the MPPT controller is used to change the duty cycle of the converter.

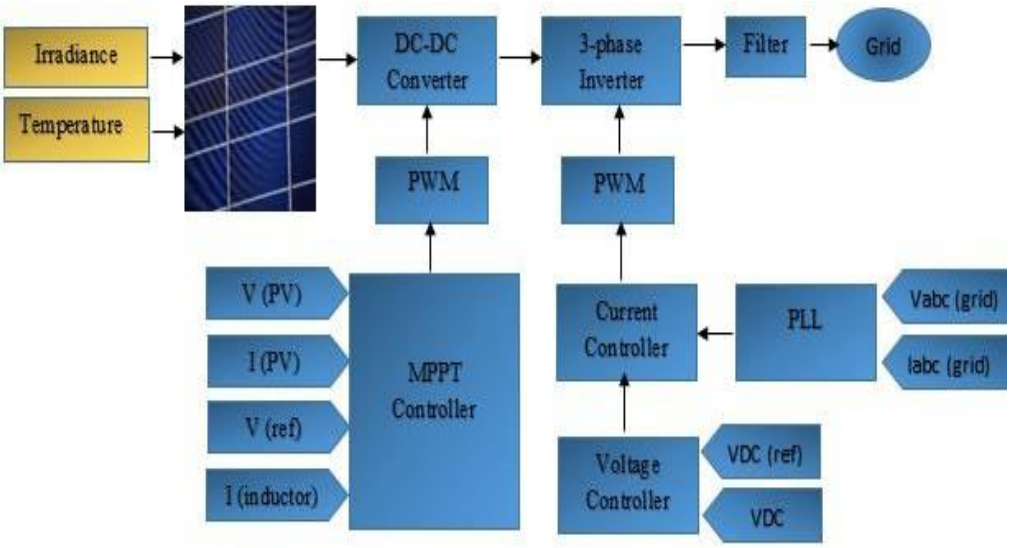

Figure 3.1: Block Diagram

System Modeling

a. PV Array

Electricity is produced by a PV array when sunlight hits a PV cell. A diode with typical PN connections makes up a PV cell. PV cells transform both kinds of radiation [41].

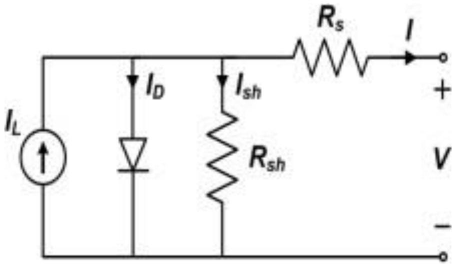

Figure 3.2: Equivalent Circuit of the PV Cell [41]

In this case, IL and irradiance are directly correlated. The equation below shows I, or area current, of a PV cell.

$$\mathbf{I} = \mathbf{I_L} - \mathbf{I_D} - \mathbf{I_{Rsh}} \qquad (3.1)$$

$$\mathbf{I = I_L - I_O\left(e^{\left(\frac{V+IRS}{nVT}\right.} - 1\right) - \frac{V+IRS}{Rsh}} \qquad (3.2)$$

$$\mathbf{I_D = I_O\left(e^{\left(\frac{V+IRS}{nVT}\right)} - 1\right)} \qquad (3.3)$$

$$\mathbf{I_{Rsh} = \frac{V + IRS}{Rsh}} \qquad (3.4)$$

$$\mathbf{V_T = \frac{kT}{q} = \frac{T}{11600}} \qquad (3.5)$$

$$\mathbf{I_O = kT^m e^{\left(\frac{-VGU}{n\,VT}\right)}} \qquad (3.6)$$

The PV cell operates most efficiently at a certain temperature and irradiation level.

$$\mathbf{P_{mpp} = V_{mpp} I_{mpp}} \qquad (3.7)$$

b. Buck Boost Converter

MPP happens near the knee of the I-V curve. The output power is at its highest at this MPP point. Therefore, a control mechanism is needed to earn an MPP point. To obtain the highest output power, a tracker is thus needed to follow the variations in the external circumstances, because it is impossible to detect or regulate the temperature and radiation [43].

$$\mathbf{\frac{V_{OUT}}{V_{IN}} = \frac{D}{1 - D}} \qquad (3.8)$$

$$\mathbf{\frac{I_{OUT}}{I_{IN}} = \frac{1 - D}{D}} \qquad (3.9)$$

$$\mathbf{V_{OUT} = I_{OUT} R_{OUT}} \qquad (3.10)$$

The representation of the equivalent resistance is:

$$\mathbf{Re\,(D, Rout) = \left(\frac{1 - D}{D}\right)^2 R_{OUT}} \qquad (3.11$$

The changing angle equation is given below:

$$\mathbf{\theta_{Re}(D, Rout) = tan^{-1} \frac{D}{(1 - D)^2}} \qquad (3.12)$$

Thus, the graph showing its operational region is obtained as shown in Figure. 3.3.

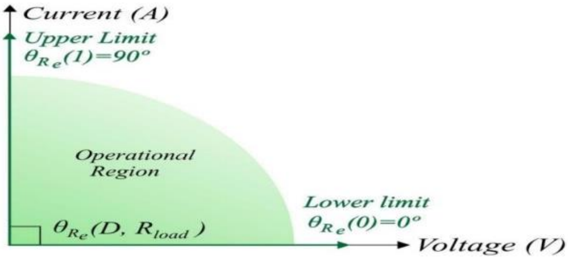

Figure 3.3: Operational Region of Buck-Boost Converter [43]

c. MPPT Controller

❖ conventional Sliding Mode Control (SMC)

The switching surface is described in terms of mistakes for this MPPT controller. The enforcement of sliding mode along specified surfaces is then accomplished using a control law. As a consequence, the systems trajectories are pointed in the direction of the appropriate sliding manifolds.

Now the sliding manifold of SMC

$$\mathbf{S = Vpv - Vpvref} \qquad (3.13)$$

Now taking the derivative of equation (3.13) we get

$$\mathbf{\dot{S} = V\dot{p}v - Vpvref} \qquad (3.14)$$

For equivalent control Uequ, from [42] we have

$$\mathbf{V\dot{p}v = \frac{Ipv}{Ci} - Uequ\,\frac{IL}{Ci}} \qquad (3.15)$$

Putting equation (3.15) into equation (3.14)

$$\dot{\mathbf{S}} = \frac{\mathbf{Ipv}}{\mathbf{Ci}} - \mathbf{Uequ}\frac{\mathbf{L}}{\mathbf{Ci}} - \mathbf{Vpvref} \qquad (3.16)$$

To calculate the equivalent control Uequ, put *S*=0

$$\mathbf{Uequ} = (-\mathbf{Vpvref}\ + \frac{\mathbf{Ipv}}{\mathbf{Ci}})\frac{\mathbf{Ci}}{\mathbf{IL}} \qquad (3.17)$$

In this strategy, a strong reachability of the following form is considered:

$$\mathbf{Usw}\ =\ -\mathbf{k1\ sign}\ (\mathbf{S}) - \mathbf{k2}(\mathbf{S}) \qquad (3.18)$$

Comparing these equation, control law becomes:

$$\mathbf{Uc}\ =\ \mathbf{Uequ}\ +\ \mathbf{Usw} \qquad (3.19)$$

- **Higher-order Sliding Mode Control (HOSMC)**

Chattering occurs across the switching manifold in the traditional SMC. This chattering reduces precision and leads to unintended mechanical component wear, which results in heat loss.

$$\mathrm{Usw}\ =\ -\mathbf{a}\sqrt{|\mathbf{S}|\mathbf{sign}}(\mathbf{S}) +\ \mathbf{W} \qquad (3.20)$$

$$\mathbf{W}\ =\ -\mathbf{b\ sign}\ (\mathbf{S})$$

The first term in 3.20 features an adaptive gain that shows how much chattering is reduced as S gets closer to zero.

$$\dot{\mathbf{S}} =\ \mathbf{V\dot{p}v}\ -\ \mathbf{Vpvref} \qquad (3.21)$$

For equivalent control Uequ, from [42] we have

$$\mathbf{V\dot{p}v} = \frac{\mathbf{Ipv}}{\mathbf{Ci}} - \mathbf{Uequ}\frac{\mathbf{IL}}{\mathbf{Ci}} \qquad (3.22)$$

$$\mathbf{S} = \frac{\mathbf{Ipv}}{\mathbf{Ci}} - \mathbf{Uequ}\frac{\mathbf{IL}}{\mathbf{Ci}} -\ \mathbf{Vpvref} \qquad (3.23)$$

To calculate the equivalent control, put *S*=0

$$\mathbf{0} = \frac{\mathbf{Ipv}}{\mathbf{Ci}} - \mathbf{Uequ}\frac{\mathbf{IL}}{\mathbf{Ci}} -\ \mathbf{Vpvref}$$

$$\mathbf{Uequ} = \left(-\ \mathbf{Vpvref} + \frac{\mathbf{Ipv}}{\mathbf{Ci}}\right)\frac{\mathbf{Ci}}{\mathbf{IL}} \qquad (3.24)$$

By comparing (3.20) and (3.24), final control law becomes:

$$\mathbf{Uc}\ = \left(-\ \mathbf{V\dot{p}v} + \frac{\mathbf{Ipv}}{\mathbf{Ci}}\right)\frac{\mathbf{Ci}}{\mathbf{IL}} + (-\ -\mathbf{a}\sqrt{|\mathbf{S}|\mathbf{sign}}(\mathbf{S}) - -\mathbf{b}\int \mathbf{sign}\ (\mathbf{S}) \qquad (3.25)$$

d. Three Phase Voltage Source inverter (VSI)

The inverter is used in a grid-connected PV system to convert the direct current DC to alternating current AC [45] [46].

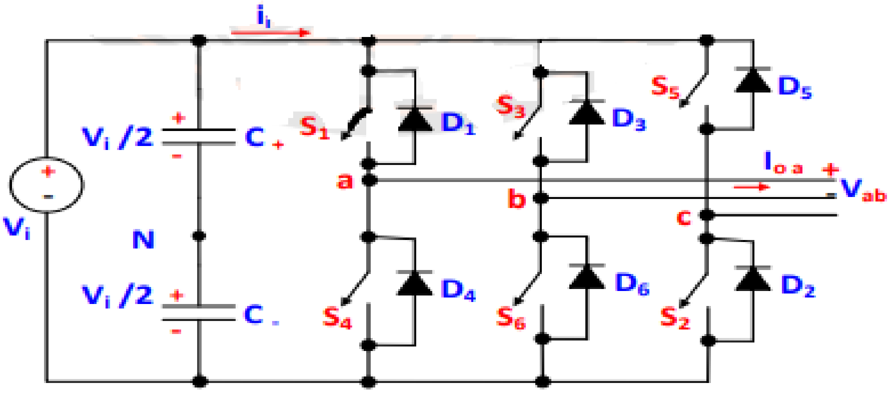

Figure 3.4: Topology of three-phase VSI [46]

The eight conceivable states of witches are compared in four different ways.

The power delivered to the load is often controlled using one of three popular techniques pulse-width modulation PWM, pulse-frequency modulation PFM, and pulse-amplitude modulation.

Table 1: State Of Three Phase Vsi [46]

State	Switch status	Vab	Vbc	Vac
1	S1, S2, S6 (on) S4, S5, S3 (off)	Vi	0	-Vi
2	S2, S3, S1 (on) S5, S6, S4 (off)	0	Vi	-Vi
3	S3, S4, S2 (on) S6, S1, S5 (off)	-Vi	Vi	0
4	S4, S5, S3 (on) S1, S2, S6 (off)	-Vi	0	Vi
5	S5, S6, S4 (on) S2, S3, S1 (off)	0	-Vi	Vi
6	S6, S1, S5 (on) S3, S4, S2 (off)	Vi	-Vi	0
7	S1, S3, S5 (on) S4, S6, S2 (off)	0	0	0
8	S4, S6, S2 (on) S1, S3, S5 (off)	0	0	0

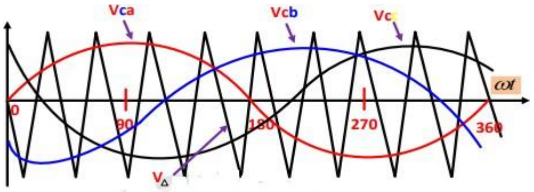

Figure 3.5: Carrier Based PWM [46]

e. Inverter Controller

A control structure of the inverter handles everything from grid synchronization to the regulation of power flow, including pulse width modulation PWM of the inverter [47].

A phase lock loop is used to retrieve the grids phase information PLL. Voltage and current are transformed dq using the phase angle that was received from this PLL. Two control loops are used to balance the flow of power on the DC and AC sides and to improve the quality of the electricity provided to the grid.

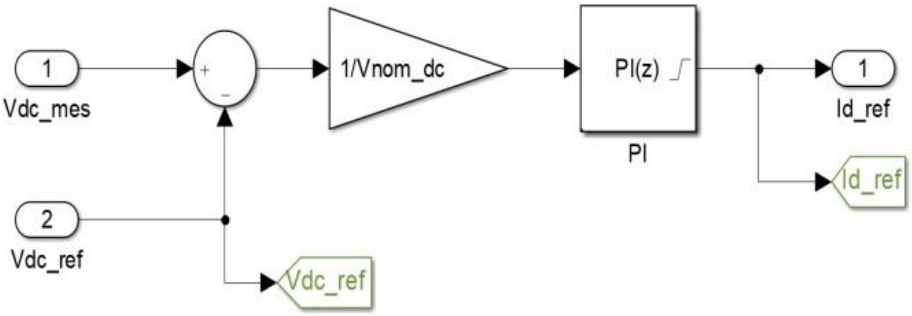

Figure 3.6: Simulink Model of Voltage Controller

Current loop controller is shown in Figure 3.7 given below

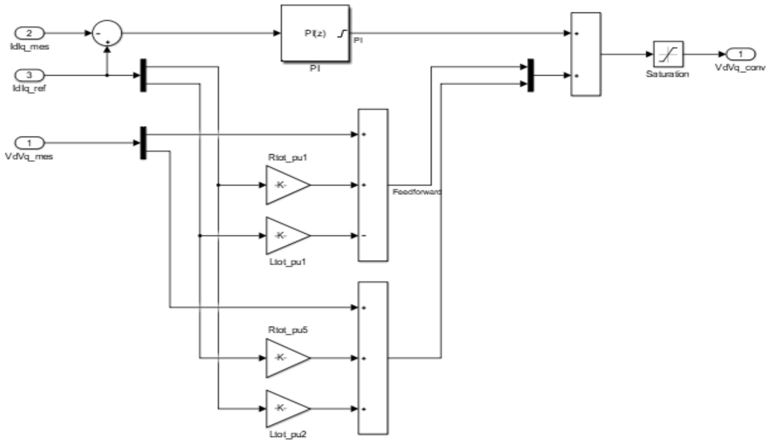

Figure 3.7: Simulink Model of Current Controller

f. Filter

The grid and inverter are connected by an LCL filter. The inverter uses switching devices, and the switches are given gating signals.

$$L_i = \frac{VDClink}{16fs\Delta IL} \qquad 3.26$$

The inductance of grid side is sized as

$$Lg = 0.6 * LI \qquad (3.27)$$

Damping resistor is also added in series with LCL filter capacitor for increasing the filter performance.

$$R_d = \frac{1}{3\omega^\circ cf} \qquad (3.28)$$

Resonance frequency of filter is calculated as

$$f0 = \frac{1}{2\pi}\sqrt{\frac{Li + Lg}{Li\ cf\ Lg}} \qquad (3.29)$$

g. Grid

Between the filter and the utility grid, a three-phase coupling transformer with a 100kVA and 260V/25kV rating is attached. Utility grid models consist of 120kV equivalent transmission networks and 25kV distribution feeders.

Simulink Model

The model of single phase grid connected photovoltaic cell with MPPT is given below.

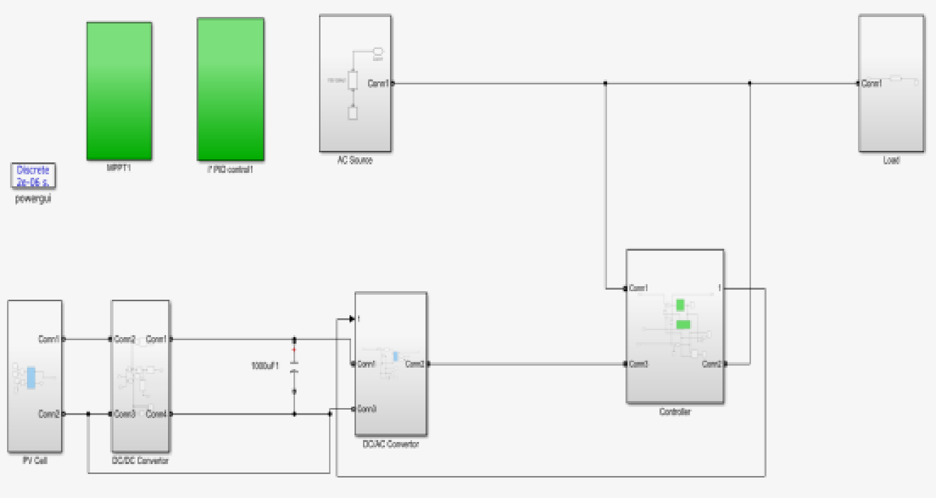

Figure 3.8: Simulink Model

a. Photovoltaic Cell

The PV cell is designed according to the parameters given.

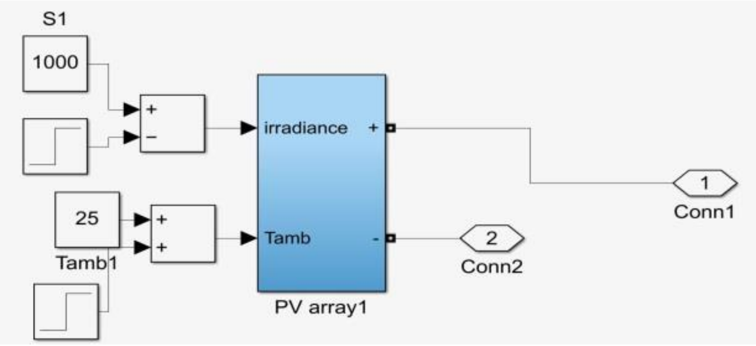

Figure 3.9: Photovoltaic Cell

The model of DC/AC converter is shown in Figure.

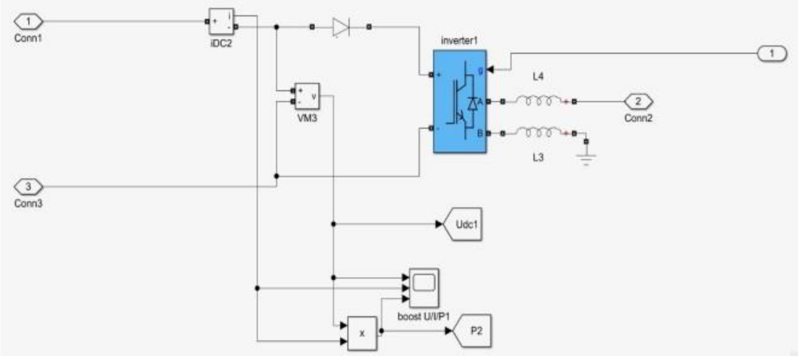

Figure 3.10: Model of DC/AC Converter

The model of control system is shown below in Figure.

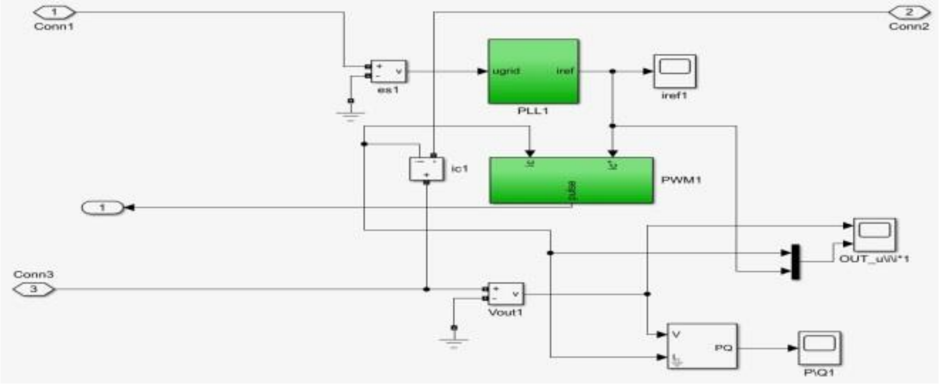

Figure 3.11: Model of Control System

IV. RESULTS

a. DC Voltage of PV

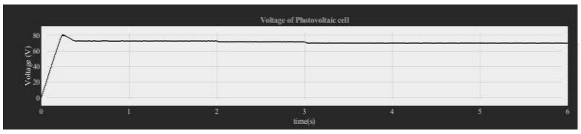

Figure 4.1: DC Voltage of PV

b. DC Current of PV

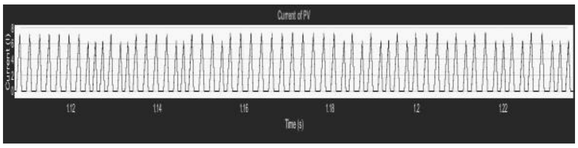

Figure 4.2: DC Current of PV

c. Power of PV

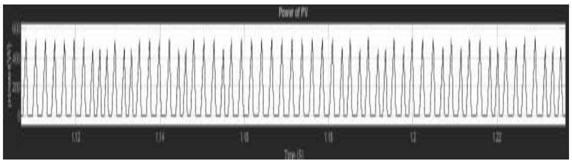

Figure 4.3: Power of PV

d. Voltage and Current after DC/AC Converter

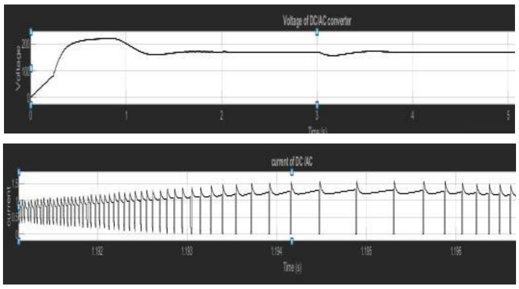

Figure 4.4: Power of PV

e. Power of DC/AC Converter

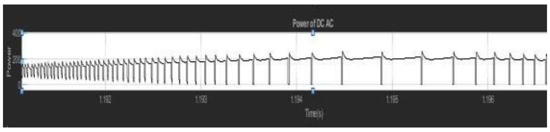

Figure 4.5: Power of DC/AV Converter

f. Sinusoidal results of voltage and current after mitigation of harmonics

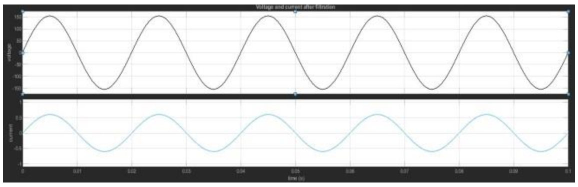

Figure 4.6: Sinusoidal results of voltage and current after mitigation of harmonics

V. CONCLUSION

The analysis and comparison of sliding mode control methods for MPPT is the main goal of this thesis. In addition, we want to apply a non-linear higher-order sliding mode MPPT control method to handle a PV systems non-linear behavior. Variable temperature and constant irradiance and constant temperature and variable irradiance are the circumstances that are used to assess the performance of the two approaches, super-twisting algorithm STA and conventional sliding mode control SMC.

VI. FUTURE WORK

Future work must be done properly on the inverter stage, where STA can also be used to improve power quality by removing current harmonics, but for now, our main focus is on analyzing and contrasting traditional SMC and STA for MPPT in grid-connected solar PV systems.

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