Chapter 5

Charging Strategies for Solar-to-Vehicle (S2V) systems using Boost Converters

5.1 Introduction

The integration of renewable energy sources into the energy infrastructure is a critical step toward achieving sustainability and reducing the environmental impact of traditional energy systems. Among these sources, solar photovoltaic (PV) systems stand out because they convert sunlight directly into electrical energy. With the increasing demand for EVs, there is a growing need to enhance the efficiency and reliability of PV systems for EV charging applications. In the previous chapter, the Chattering effect was a serious issue in power converters using SMC, characterized by high-frequency oscillations that can lead to mechanical wear and increased energy losses. In this chapter, the chattering effect is mitigated by the super-twisting algorithm with the proposed converter. This chapter introduces a novel approach for maximizing power point tracking (MPPT) in solar PV systems, specifically designed to address the unique challenges of charging EVs.

Implementation Considerations

- **MPPT Algorithm Selection:** Common algorithms include Perturb and Observe

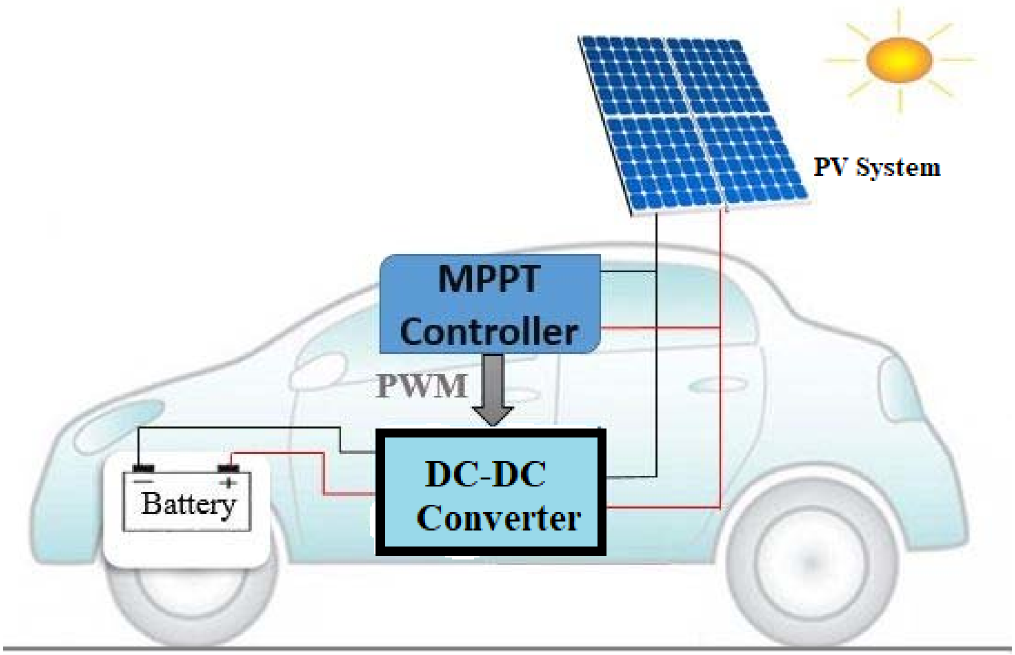


Figure 5.1: The schematic of the EV charging system integrated with a PV system.

(P&O), Incremental Conductance, and Particle Swarm Optimization. The MPPT algorithm's choice affects the charging process's efficiency and stability. MPPT algorithm's choice affects the charging process's efficiency and stability.

- **Boost Converter Design:** The design must ensure high efficiency, fast response to changes in irradiance, and stability under varying load conditions.

- **Battery Compatibility:** The charging methodology must be compatible with the specific battery chemistry used in the EV to avoid damage and ensure optimal performance.

- **System Integration:** The seamless integration of the PV panels, boost converter, MPPT controller, and BMS is crucial for efficient and reliable operation.

- **Control Algorithms:** Implement MPPT and manage the boost converter to maintain optimal charging conditions.

5.2 Solar to Vehicle (S2V) EV Charging Systems

Charging EVs directly from solar photovoltaic (PV) systems demands efficient power conversion and control strategies to maximize energy transfer and ensure reliable operation. One effective approach uses a boost converter to elevate the voltage from the PV panels to the level required for charging the EV battery. This section explores various methodologies for charging EVs using an S2V system with an integrated boost converter.

- ***Constant Voltage Charging:*** In this methodology, the boost converter adjusts the voltage output to a constant value suitable for the EV battery. The MPPT controller ensures the PV panels operate at their maximum power point.

  Advantages: (i) This method simplifies the control strategy as the voltage is maintained constantly.

  (ii) It provides a stable and consistent charging process, which can help prolong battery life.

  Disadvantages: (i) Solar power may not be fully utilized during varying irradiance conditions.

  (ii) If the SoC of the battery is not adequately monitored, there may be a risk of overcharging.

- ***Constant Current Charging:*** The boost converter provides a steady level of current control. The voltage may change depending on the PV output and battery condition, and the PV output is optimized using the MPPT controller.

  Advantages:

  (i) It provides a steady current, which benefits some battery chemistries.

  (ii) it can be combined with constant voltage charging in a two-stage procedure to improve battery performance and life.

  Disadvantages:

  (i) To prevent battery damage, accurate current control is necessary.

  (ii) If there are significant fluctuations in the PV output, efficiency may suffer.

- ***Two-Stage Charging:*** This method combines constant current and constant voltage charging. Initially, the boost converter supplies a constant current until the bat-

tery reaches a specific voltage, then switches to constant voltage mode to complete the charging.
(i) *Optimized Charging Speed:* The constant current stage allows for rapid charging, while the constant voltage stage ensures the battery is fully charged without overcharging.
(ii) *Enhanced Battery Lifespan:* By avoiding overvoltage and excessive heat generation, the two-stage method helps maintain battery health over the long term.
(iii) *Efficient Energy Use:* Maximizes available solar energy, especially when paired with an MPPT controller.
(iv) *Versatility:* Suitable for various battery chemistries, including lithium-ion, lead-acid, and others.

- ***Pulse Charging:*** Pulse charging delivers intermittent current pulses to the battery. The boost converter and MPPT controller work together to optimize PV output.

  Advantages:

  (i) It Can reduce charging time and improve battery efficiency.

  (ii) It can minimize thermal stress on the battery.

  Disadvantages:

  (i) Complexity: It requires advanced control systems and increasing costs.

  (ii) EMI: High-frequency pulses can interfere with nearby electronics.

  (iii) Compatibility: Not all batteries respond well, risking damage if not managed.

  (iv) Heat: It can generate excess heat, necessitating additional cooling.

  (v) Limited Application: Not universally applicable across all batteries and scenarios.

  (vi) Accuracy: It requires precise tuning of parameters for optimal performance.

- ***Adaptive Charging:*** Adaptive charging dynamically adjusts charging parameters based on real-time feedback from the PV system and battery state of charge. The boost converter, MPPT controller, and BMS collaborate to optimize the process.
  (i) It maximizes solar power utilization.

(ii) It enhances battery health by adapting to its needs.

Advantages of S2V EV Charging Systems

- ***Environmental Benefits:*** Using renewable solar energy reduces greenhouse gas emissions and reliance on fossil fuels.
- ***Cost Savings:*** Lowers electricity costs using free solar energy, especially in sunny regions.
- ***Energy Independence:*** It decreases dependence on grid power, enhancing energy security and resilience.
- ***Scalability:*** It Can be scaled up or down based on the available solar capacity and EV charging requirements.
- ***Sustainability:*** It promotes sustainable transportation by integrating clean energy sources with electric mobility.

5.3 MPPT and Super Twisting Algorithms (STA)

The primary focus of this approach is utilizing a super-twisting controller (STC) to achieve efficient MPPT in PV systems. The STC is adept at regulating the power output of PV panels by accurately tracking their maximum power points. This capability is crucial for optimizing the performance of PV systems, especially under varying environmental conditions such as changes in irradiance and temperature. The methodology integrates an STC designed to enhance the efficiency of MPPT in PV arrays. Unlike traditional sliding mode controllers, the STC method effectively minimizes chattering and improves the accuracy of tracking the maximum power points (MPP) of PV panels. The primary objective of this research is to propose a reliable and efficient technique to regulate the power output of PV panels, which is crucial for optimizing the charging process of EVs using solar energy. The proposed STC-based MPPT technique is compared against the conventional perturb and observe (P&O) method under various environmental conditions, including irradiance and temperature fluctuations.

The increasing adoption of EVs and the growing demand for sustainable energy solutions has led to a surge in interest in S2V charging systems. PV systems integrated with EV charging stations offer a promising solution to provide clean and renewable energy for EVs, reducing carbon emissions and dependence on conventional fossil fuels. In such solar-based charging systems, it is crucial to maximize the power output from the PV panels to charge efficiently EVs. The MPPT technique plays a vital role in achieving this objective. The objective of MPPT is to ensure that the PV system operates at or near its maximum power point (MPP) at all times. This maximizes the power harvested from the PV array [147]. To charge a battery efficiently using solar power, an MPPT controller continuously adjusts the voltage and current output from the PV panels to match the battery's charging requirements. When the PV array is operating at its MPP delivers the maximum power to the battery for a given set of environmental conditions (insolation, temperature, etc.) [148, 149].

To address the chattering issue, as previously discussed, this chapter introduces an STC. Among the array of MPPT techniques, STC has emerged as a pioneering and effective method for PV systems in applications related to S2V charging. Known for its robustness and adaptive nature, STC stands out for its capability to track the maximum power point swiftly and precisely, especially in situations where environmental conditions fluctuate rapidly.

This chapter makes significant contributions in the following ways:

(i) It introduces a novel MPPT controller designed for PV systems that effectively mitigates chattering issues while ensuring robustness and finite-time convergence properties even amidst varying solar irradiance, parametric uncertainties, and external disturbances.

(ii) The chapter also presents an STC approach tailored for DC-DC boost converters aimed at achieving rapid tracking of MPPT and minimizing the adverse effects of DC-link voltage pulsations.

Key Contributions:

Development of a Super-Twisting MPPT Controller:

(i) Designed specifically for PV systems to address the chattering issue.

(ii) Ensures robustness under varying insolation levels and temperatures.

Efficiency and Speed in Battery Charging:

(i) Utilizes super-twisting MPPT algorithms to achieve maximum power output.

(ii) Results in fast charging of EV batteries.

Extension of Battery Life:

(i) Reduces dependency on grid charging.

(ii) Optimizes the use of renewable energy, thereby extending the battery life of EVs.

5.4 Modeling and Control of S2V Charger using STA

In recent years, the demand for efficient and reliable EV charging solutions has surged, driven by the global push towards sustainable transportation. The transition to renewable energy sources, particularly solar energy, is pivotal in meeting these demands. This chapter focuses on developing and implementing a Solar-to-Vehicle (S2V) charger utilizing the Super-Twisting Algorithm (STA) for MPPT. The STA-based MPPT method mitigates the limitations of conventional methods in the following ways:

(i) Enhanced Power Utilization: While conventional constant voltage charging may not fully utilize solar power due to irradiance variations, the STA technique ensures precise and rapid tracking of the Maximum Power Point (MPP) under fluctuating environmental conditions. This maximizes the available solar power for charging.

(ii) Minimized Overcharging Risks: The adaptive nature of the STA helps regulate the power output dynamically, preventing excessive charging when the battery State of Charge (SoC) is high. This overcomes the risk of overcharging associated with fixed voltage charging.

(iii) Improved Stability and Efficiency: The chattering-free nature of the STA method enhances the stability of the charging process. Unlike traditional controllers that may introduce power oscillations, the STA minimizes switching losses and improves overall efficiency.

(iv) Minimized Chattering and Improved Stability: Unlike conventional MPPT methods such as perturb and observe (P&O), STA significantly minimizes chattering effects, leading to smoother power output regulation and enhanced reliability in EV charging.

5.4.1 Integration of PV Panels with Boost Converter in an EV Battery Charging System

In this section, we demonstrate the integration of PV panels with a boost converter in an EV battery charging system. This configuration ensures efficient energy conversion and maximizes the power transfer from the PV panels to the EV battery.

(i) System Configuration PV Panels:

The PV panels are the primary renewable energy source, converting sunlight into electrical energy. PV charging refers to the charging of the EV solely by the PV power. However, the PV array must be sufficiently large to fulfill the charging requirement for the designated number of vehicles.
There are two main approaches to achieving the charging goals:
(1) By the direct PV to the EV connection, as shown in Fig. 5.2 (a), and
(2) with an intermediate energy storage unit (ESU), as shown in Fig. 5.2(b) and (c).

In PV charging systems, MPPT is essential, particularly when charging batteries with solar panels. The primary function of MPPT is to optimize the solar energy conversion process, ensuring that the maximum available power from the solar panels is used to charge the batteries. By implementing MPPT, the charging current can be optimized, leading to faster and more efficient battery charging, even under varying irradiance and temperature conditions. MPPT enables the solar panels to capture the maximum amount of solar energy and transfer it to the battery, thereby maximizing the overall efficiency of the system. Fig.5.3 depicts the block diagram of an MPPT controller.

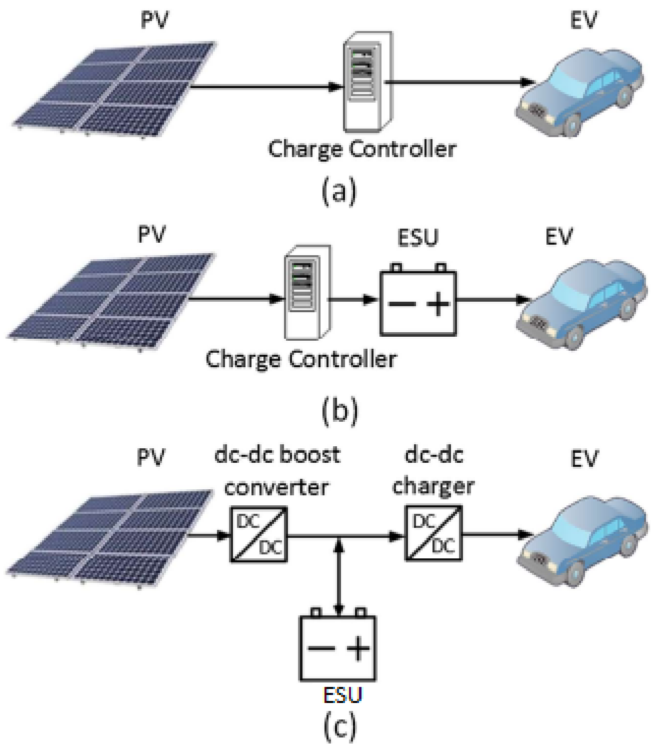


Figure 5.2: Block diagram of MPPT controller.

(ii) PV Charging and Boost Converter Model

The PV panels are connected to the boost converter's input terminals. Voltage and current matching ensures that the output voltage of the PV panels is within the operational range of the boost converter.

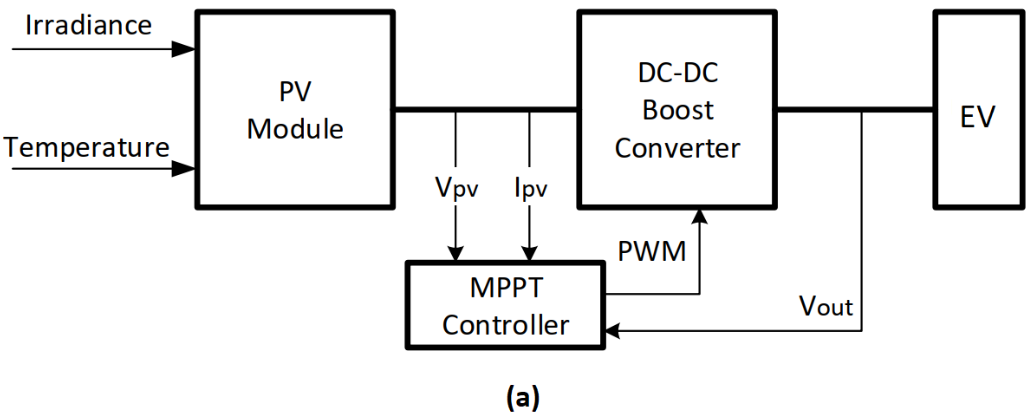
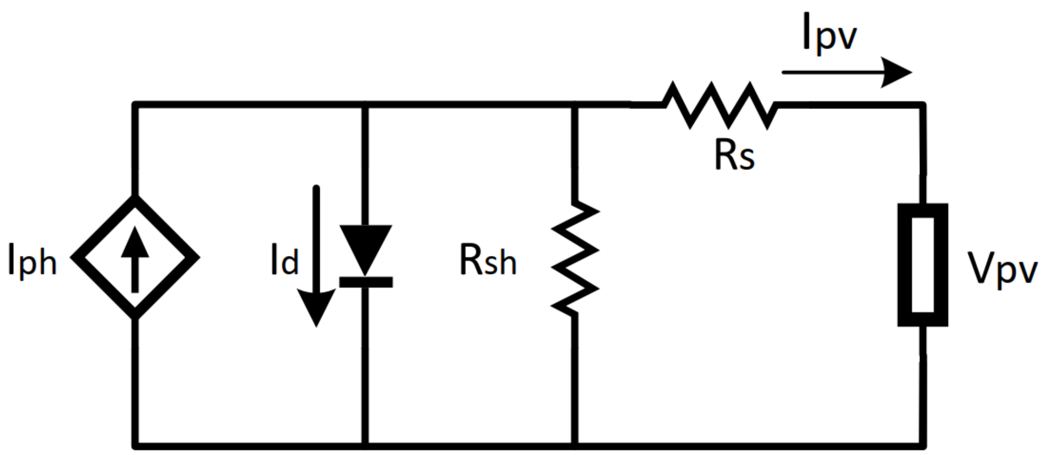
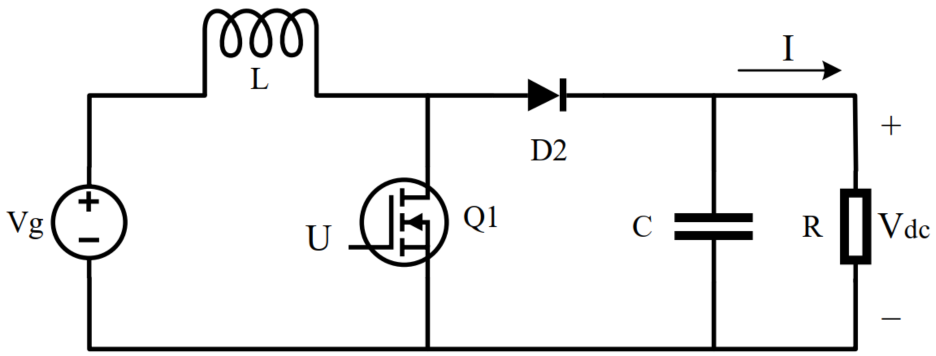


Figure 5.3: Block diagram of MPPT controller.



(b)

Figure 5.4: A single PV module.



(c)

Figure 5.5: DC-DC boost converter.

Fig. 5.4 illustrates the schematic circuit of the PV module. Furthermore, 1-V and P-V characteristics of PV cells are discussed to get MPPT-based charging of the battery. The performance of PV panels depends on factors such as insolation levels, temperature, and shading, which affect the voltage-current (V-I) and power-voltage (P-V) characteristics.

(i) I-V and P-V characteristics of the module at different solar insolation levels: The I-V (current-voltage) and P-V (power-voltage) characteristics of a PV module vary significantly with changes in insolation, which is the amount of solar radiation received by the module. With variations in insolation levels, the maximum power available from the solar source varies, as depicted in Fig. 5.6, with values of 400W, 600W, 800W, and 1000W. As the insolation level changes, the maximum power output also varies.

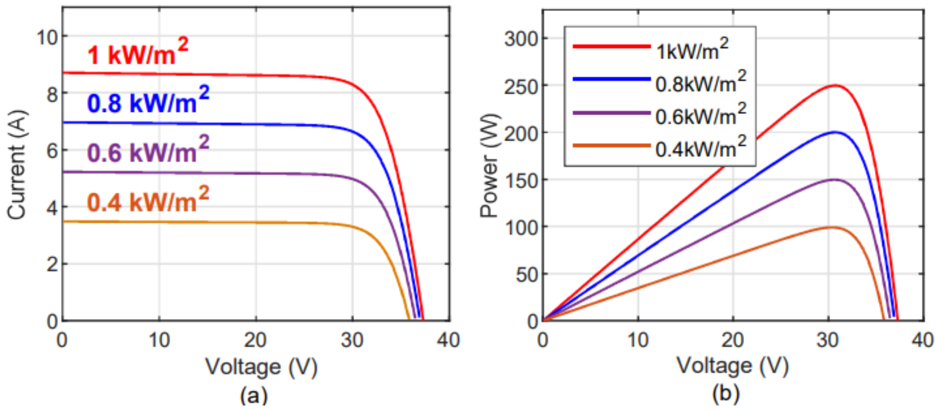


Figure 5.6: (a) I-V; (b) P-V characteristics under different insolation levels.

(ii) I-V and P-V characteristics of the module at different temperatures: A PV module's I-V and P-V characteristics are critical in understanding its performance and efficiency under various conditions. Temperature plays a significant role in these characteristics, so analyzing how they change with temperature variations is useful. With variations in temperature, the maximum power available from the solar source varies, as depicted in Fig. 5.7, with values of $45°C$, $35°C$, $25°C$, and $15°C$. As temperature changes, the maximum power output also varies. Therefore, an effective MPPT system must be capable of adapting to these changes and delivering the required output current for battery charging. When the maximum power is high, insolation levels are also elevated.

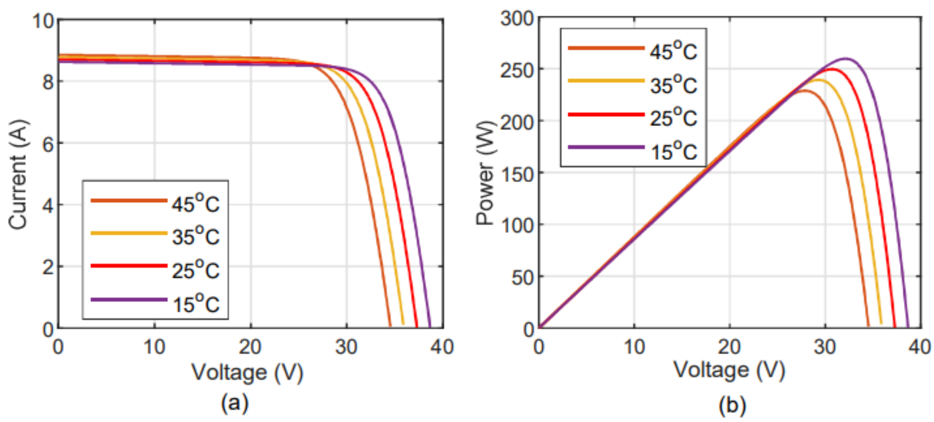


Figure 5.7: (a) I-V; (b) P-V characteristics under different insolation levels.

As a result, the charging current needs to be proportionately high. This current should be aligned with the maximum power available from the solar panel, which varies with the insolation level. A higher charging current facilitates faster battery charging. To achieve this, two key components are necessary: (i) a DC/DC converter and (ii) an MPPT algorithm [150]. These methods will be further elaborated in the next section.

5.4.2 DC-DC Boost Converter Model

In the circuit shown in Fig. 5.5, the components are defined as follows: L represents the inductor, Q_1 is the power semiconductor switch, V_g denotes the supply voltage, C represents the capacitor, R signifies the load resistance and D_2 denotes the power semiconductor diode. Additionally, V_{dc} and I represent the output voltage and current, respectively. When the switch is turned on, the resulting dynamics are

$$\begin{cases} \frac{dI_L}{dt} &= \frac{V_g}{L} \\ \frac{dV_{dc}}{dt} &= -\frac{V_{dc}}{RC}. \end{cases} \tag{5.1}$$

When the switch is turned off, the resulting dynamics are

$$\begin{cases} \frac{dI_L}{dt} &= -\frac{V_{dc}}{L} + \frac{V_g}{L} \\ \frac{dV_{dc}}{dt} &= \frac{I_L}{C} - \frac{V_{dc}}{RC}. \end{cases} \tag{5.2}$$

Based on the Figs. 5.4 and 5.5, $V_{pv} = V_g$ and $I_L = I_{pv}$, then after combining (5.1) and (5.2), yields

$$\begin{cases} \frac{dI_{pv}}{dt} &= -(1-\Sigma)\frac{V_{dc}}{L} + \frac{V_{pv}}{L} \\ \frac{dV_{dc}}{dt} &= (1-\Sigma)\frac{I_{pv}}{C} - \frac{V_{dc}}{RC} \end{cases} \tag{5.3}$$

where Σ denotes the switching position of the boost converter.

One can write (5.3) as follows

$$\frac{dI_{pv}}{dt} = -(1-u)\frac{V_{dc}}{L} + \frac{V_{pv}}{L} \tag{5.4}$$

$$\frac{dV_{dc}}{dt} = (1-u)\frac{I_{pv}}{C} - \frac{V_{dc}}{RC} \tag{5.5}$$

where u is the control input of the boost converter.

5.5 MPPT Controller Design

MPP's location varies continuously according to irradiance and temperature, so tracking algorithms must be used to determine its location. Therefore, it becomes essential to implement MPPT techniques for the PV module. The load impedance $R = \frac{V_{dc}}{I}$. Assume, I_α and V_α is MPP current and voltage, respectively. Then, PV optimal load $R_{op} = \frac{V_\alpha}{I_\alpha}$. PV systems transfer maximum power when $R = R_{op}$.

5.5.1 Sliding Surface Design

To achieve the maximum power output from the PV cell, consider the sliding surface $S = \frac{dP_{pv}}{dI_{pv}} = 0$,

$$S = \frac{dP_{pv}}{dI_{pv}} = 0 \tag{5.6}$$

where $P_{pv} = V_{pv} I_{pv}$
Rewrite the sliding surface $S = V_{pv} + I_{pv}\left(\frac{dV_{pv}}{dI_{pv}}\right) = 0$

$$S = V_{pv} + I_{pv}\left(\frac{dV_{pv}}{dI_{pv}}\right) = 0 \tag{5.7}$$

5.5.2 Super-Twisting Controller Design

For systems with relative degree-1, the STA eliminates smooth disturbances of arbitrary shape and provides finite-time convergence to the set point. The global control $u = u_{eq} + u_{st}$ consists of the two terms: (a) the equivalent control term u_{eq} (b) the super-twisting control term u_{st}.

$$u = u_{eq} + u_{st}. \tag{5.8}$$

Then u_{eq} is determined by

$$\frac{dS}{dt} = \frac{dS}{dI_{pv}} \frac{dI_{pv}}{dt} = 0 \tag{5.9}$$

$$\frac{dS}{dt} = \frac{dS}{dI_{pv}}\left(-(1-u)\frac{V_{dc}}{L} + \frac{V_{pv}}{L}\right) = 0 \tag{5.10}$$

By solving (5.10), one can obtain the equivalent control $u_{eq} = 1 - \frac{V_{pv}}{V_{dc}}$ and the

$$u_{eq} = 1 - \frac{V_{pv}}{V_{dc}}. \tag{5.11}$$

STC $u_{st} = \frac{L}{V_{dc}} \left(k_1 |S|^{\frac{1}{2}} \text{sign}(S) + k_2 \int_0^t \text{sign}(S) d\tau \right)$, where $k_1 > k_2$ and $k_2 > 0$ are the controller gains.

$$u_{st} = \frac{L}{V_{dc}} \left(k_1 |S|^{\frac{1}{2}} \text{sign}(S) + k_2 \int_0^t \text{sign}(S) d\tau \right) \tag{5.12}$$

5.5.3 Robustness and Model Uncertainty

Considering the system (5.4) in the presence of uncertainties and disturbances as follows:

$$\frac{dI_{pv}}{dt} = \left(\frac{V_{dc}}{L} - \xi_1 \right) u + \left(-\frac{V_{dc}}{L} + \frac{V_{pv}}{L} - \xi_2 \right) - \delta \tag{5.13}$$

where ξ_1 and ξ_2 are parametric uncertainties, δ is the external disturbances.
One can write (5.13) as follows:

$$\frac{dI_{pv}}{dt} = \frac{V_{dc}}{L} u - \frac{V_{dc}}{L} + \frac{V_{pv}}{L} - \Delta \tag{5.14}$$

where $\Delta \triangleq \xi_1 u + \xi_2 + \delta$ is the disturbances containing unmodeled quantities, external disturbance, and parametric uncertainties.
Based on the physical limitations and performance of the system during operation, it has been assumed that the system (5.4) has uncertainty in the inductor element L but it is bounded. The external disturbance δ is at least one time differentiable and its first derivative is bounded. $L = \bar{L} + \Delta L, \quad |\Delta L| \leq \zeta_L \quad$ and $\quad |\Delta| \leq \zeta_\Delta$, where $\bar{L}$ represents the nominal value of inductor, ΔL is its uncertainty and $\zeta_{(.)}$ are known bounded positive constants.

According to the assumption, it can be assumed that the disturbances Δ is at least one time differentiable and its first derivative is bounded $|\dot{\Delta}| \leq \zeta$, where ζ is a known bounded positive constant.

5.5.4 Stability Analysis

Considering the above disturbance, the time derivative of the sliding variable S can be written as:

$$\frac{dS}{dt} = \frac{dS}{dI_{pv}}\left(\frac{V_{dc}}{L}u - \frac{V_{dc}}{L} + \frac{V_{pv}}{L} - \Delta\right) = 0 \tag{5.15}$$

$$\frac{dS}{dI_{pv}} = 2\frac{dV_{pv}}{dI_{pv}} + I_{pv}\frac{d^2V_{pv}}{dI_{pv}^2} \tag{5.16}$$

Consider the Lyapunov function $V = \frac{1}{2}S^2$.

$$V = \frac{S^2}{2} \tag{5.17}$$

Furthermore, the first time derivative of the Lyapunov function can be expressed as:

$$\dot{V} = S\frac{dS}{dt} = S\frac{dS}{dI_{pv}}\frac{dI_{pv}}{dt} = \left[V_{pv} + I_{pv}\left(\frac{dV_{pv}}{dI_{pv}}\right)\right]\left[2\frac{dV_{pv}}{dI_{pv}} + I_{pv}\frac{d^2V_{pv}}{dI_{pv}^2}\right]\left[\frac{V_{dc}}{L}u_{st} - \Delta\right] \tag{5.18}$$

One can determine the V_{pv} from (7.2) as:

$$V_{pv} = \frac{kT}{q}\ln\left(\frac{I_{ph} + I_d - I_{pv}}{I_d}\right). \tag{5.19}$$

The first and second derivative of (5.19) with respect to I_{pv} can be expressed as:

$$\frac{dV_{pv}}{dI_{pv}} = -\frac{kT}{q}\left(\frac{I_d}{I_{ph} + I_d - I_{pv}}\right) \tag{5.20}$$

$$\frac{d^2V_{pv}}{dI_{pv}^2} = -\frac{kT}{q}\left(\frac{I_d}{(I_{ph} + I_d - I_{pv})^2}\right) \tag{5.21}$$

Since $V_{pv} > 0$ and $V_{pv} > I_{pv}\frac{dV_{pv}}{dI_{pv}}$, thus the first term of (5.18) is positive. In order to determine the sign of second term, one has to identify the sign of (5.20) and (5.21). Since $I_{ph} > I_d$ and $I_{ph} > I_{pv}$, the sign of second term of (5.18) is negative.
Therefore, (5.18)can be expressed as follows:

$$\dot{V} = -\left[\frac{V_{dc}}{L}u_{st} - \Delta\right] \tag{5.22}$$

By substituting u_{st} value into (5.22), yields

$$\dot{V} = -k_1|S|^{\frac{1}{2}}\text{sign}(S) - k_2\int_0^t \text{sign}(S)d\tau + \Delta. \tag{5.23}$$

Rewrite (5.23) as follows:

$$\dot{V} = -k_1|S|^{\frac{1}{2}}\text{sign}(S) + \Sigma, \qquad \dot{\Sigma} = -k_2\text{sign}(S) + \dot{\Delta}. \tag{5.24}$$

In (5.24), the constants $k_2 > |\dot{\Delta}|$ and $k_1 > k_2$ [151]. Therefore, it can be concluded that the $\dot{V} < 0$ and the stability is ensured.

5.6 Simulation Results

We have applied MATLAB/SIMULINK to simulate the PV cell model, DC-DC boost converter, and MPPT controller algorithms under varying irradiance and temperature conditions. In the first step, varying irradiances are used to examine MPPT's effectiveness and later varying temperatures are used to examine MPPT's effectiveness. The Soltech 1STH-250-WH PV model is selected as a PV module. The controller gains are chosen as $k_1 = 1$ and $k_2 = 0.5$. The boost converter components values are $L = 200 \times 10^{-6}H$, $C = 100 \times 10^{-6}F$ and $R = 100\Omega$.

5.6.1 Under varying irradiances

This section employed the proposed STC method and P&O method under the given conditions: solar irradiance, G = [1000-800-600-400] W/m^2, and ambient temperature, T = 25 $°C$. Figs. 5.8(a), 5.8(b) depicts the power, 5.8(c), 5.8(d) depicts the voltage, and 5.8(e), 5.8(f) illustrates the current of the PV system when utilizing the proposed STC method and the P&O method under different irradiance levels, G = [1000-800-600-400] W/m^2, and a constant temperature of T = 25 $°C$. To showcase the effectiveness of the proposed STC controller compared to the P&O method, the irradiance is sequentially changed at specific time points. Firstly, the irradiance shifts from G = 1000 W/m^2 to G = 800 W/m^2 at 0.2 seconds. Then, it transitions from G = 800 W/m^2 to G = 600 W/m^2 at 0.4 seconds, and finally from G = 600 W/m^2 to G = 400 W/m^2 at 0.6 seconds. Observing Figs. 5.8(a),

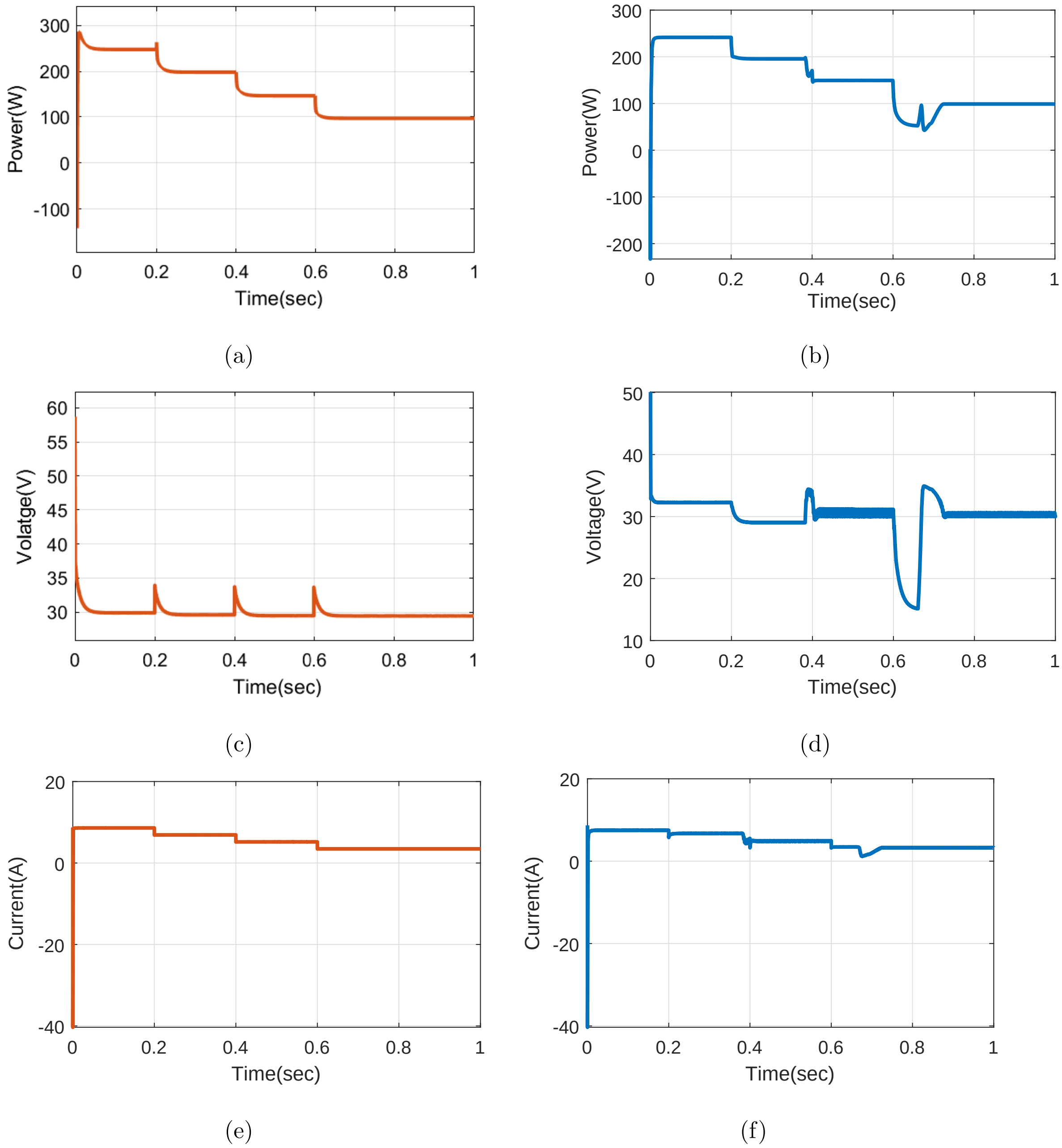


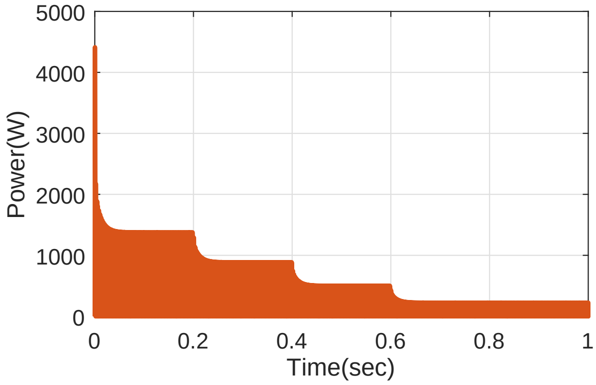
Figure 5.8: (a) PV power with STC (coral colour), (b) PV power with P&O (blue colour), (c) PV voltage with STC (coral colour), (d) PV voltage with P&O (blue colour), (e) PV current with STC (coral colour), (f) PV current with P&O (blue colour).

5.8(b), 5.8(c), 5.8(d), 5.8(e), 5.8(f), it is evident that the power output of the PV cell decreases due to the reduction in irradiance. Moreover, this proposed method exhibits improved responses with minimal fluctuations compared to the P&O method, particularly during sudden changes in irradiation at 0.2 seconds, 0.4 seconds, and 0.6 seconds. Conversely, the P&O method demonstrates significant overshoots and eventually settles at a steady state with considerable perturbations. This limitation of the P&O method is effectively addressed by the STC method.

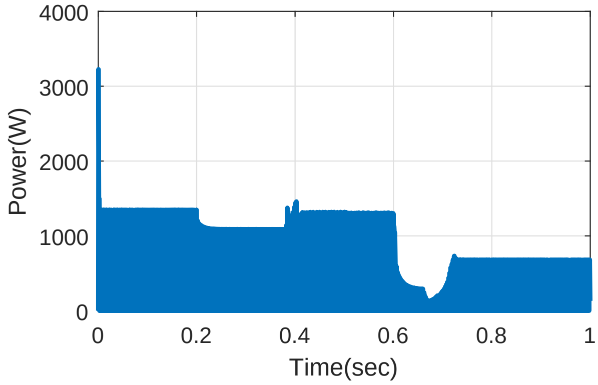
Fig. 5.9 presents the power, voltage, and current characteristics of the boost converter under different irradiance levels (G = [1000-800-600-400] W/m^2) and a temperature of T = 25 $°C$ when utilizing the STC and P&O methods. By comparing the obtained results with those of the P&O method, it can be observed from Figs. 5.9(a), 5.9(b), 5.9(c), 5.9(d), 5.9(e), 5.9(f) that there are no instances of overshoot or transient behavior when sudden changes in irradiation occur. The STC method exhibits smooth curves, enhancing performance and achieving high efficiency, which helps overcome the drawbacks of the P&O method.

5.6.2 Under varying temperatures

This section utilized the proposed STC method and P&O method under the specified conditions: $G = 1000\ W/m^2$ and $T = [45-35-25-15]°C$. The PV system's power, voltage, and current are depicted in Fig. 5.10, showcasing the comparison between the proposed STC method and the P&O method. The measurements were obtained under an irradiance level of G = 1000 W/m^2 and varying temperatures of T = [45-35-25-15] $°C$. To highlight the superior performance of the proposed STC controller over the P&O method, the temperature was intentionally adjusted at specific time intervals. At 0.2 seconds, the temperature changed from T = 45 $°C$ to T = 35 $°C$, followed by a transition from T = 35 $°C$ to T = 25 $°C$ at 0.4 seconds, and finally, a shift from T = 25 $°C$ to T = 15 $°C$ at 0.6 seconds. In Fig. 5.10, it is evident that the decrease in temperature leads to an increase in the power output of the PV cell. Furthermore, our proposed method exhibits superior responses compared to P&O methods without experiencing any fluctuations when sudden temperature changes occur at 0.2 sec, 0.4 sec, and 0.6 sec.



(a)



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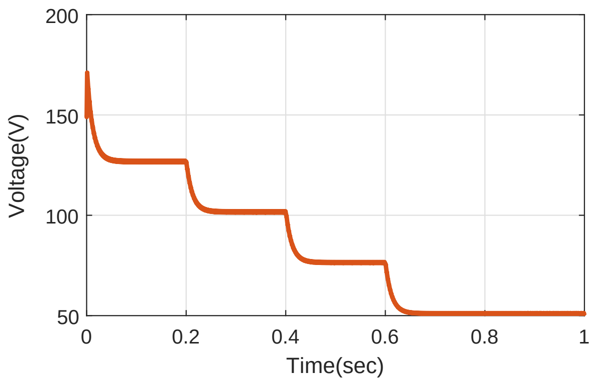

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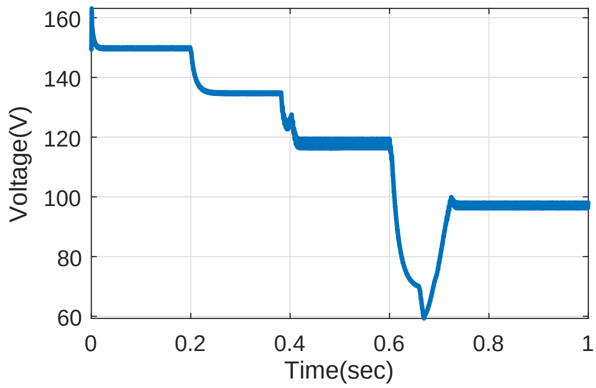
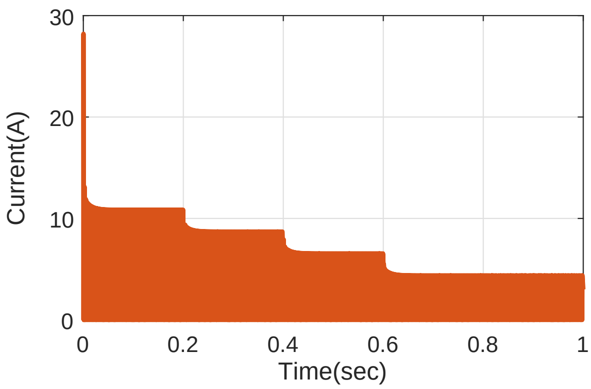
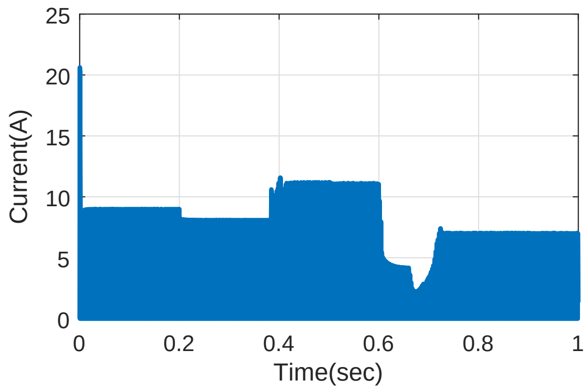


(d)

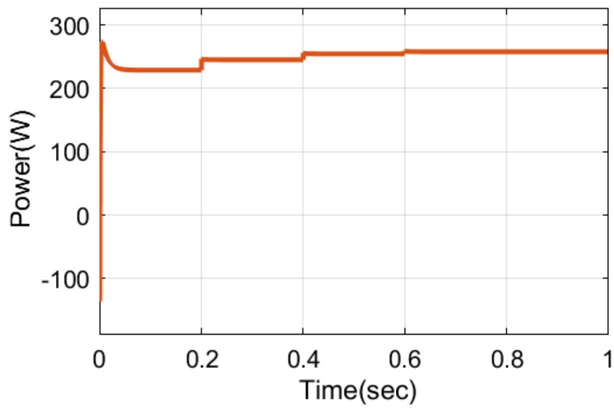


(e)

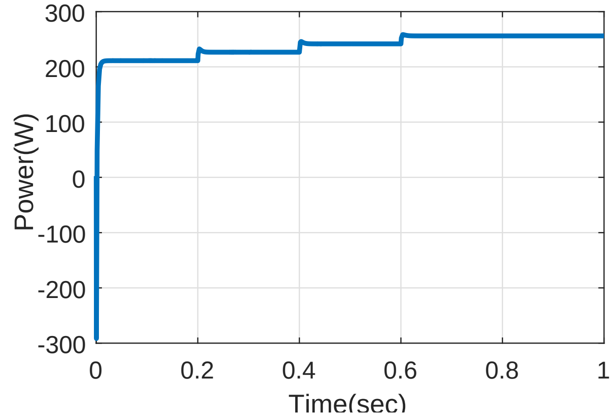


(f)

Figure 5.9: (a) Boost converter power with STC (coral colour), (b) Boost converter power with P&O (blue colour), (c) Boost converter voltage with STC (coral colour), (d) Boost converter voltage with P&O (blue colour), (e) Boost converter current with STC (coral colour), (f) Boost converter current (coral colour) with P&O (blue colour).



(a)



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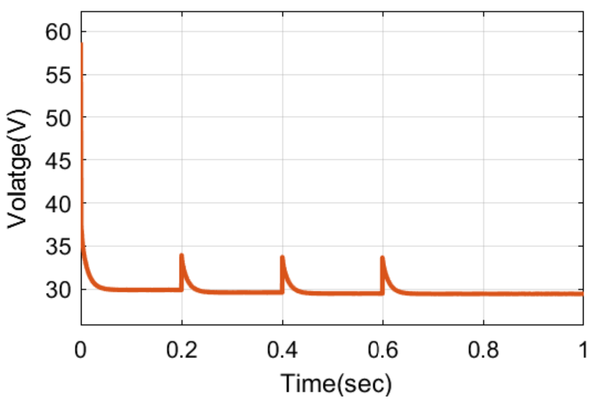
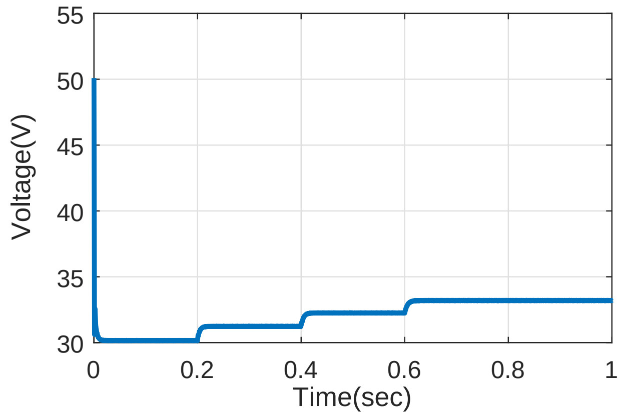


(c)



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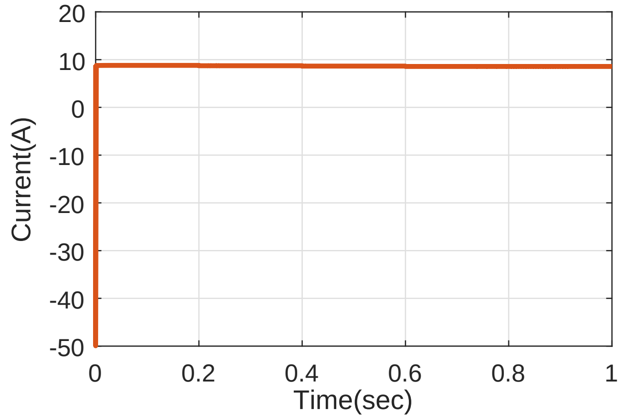
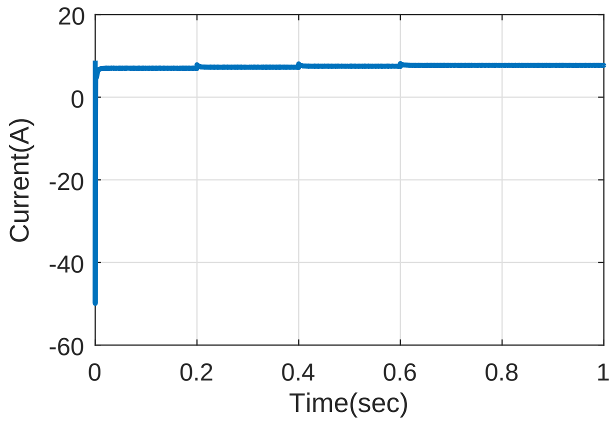


(e)



(f)

Figure 5.10: (a) PV power with STC (coral colour), (b) PV power with P&O (blue colour), (c) PV voltage with STC (coral colour), (d) PV voltage with P&O (blue colour), (e) PV current with STC (coral colour), (f) PV current with P&O (blue colour).

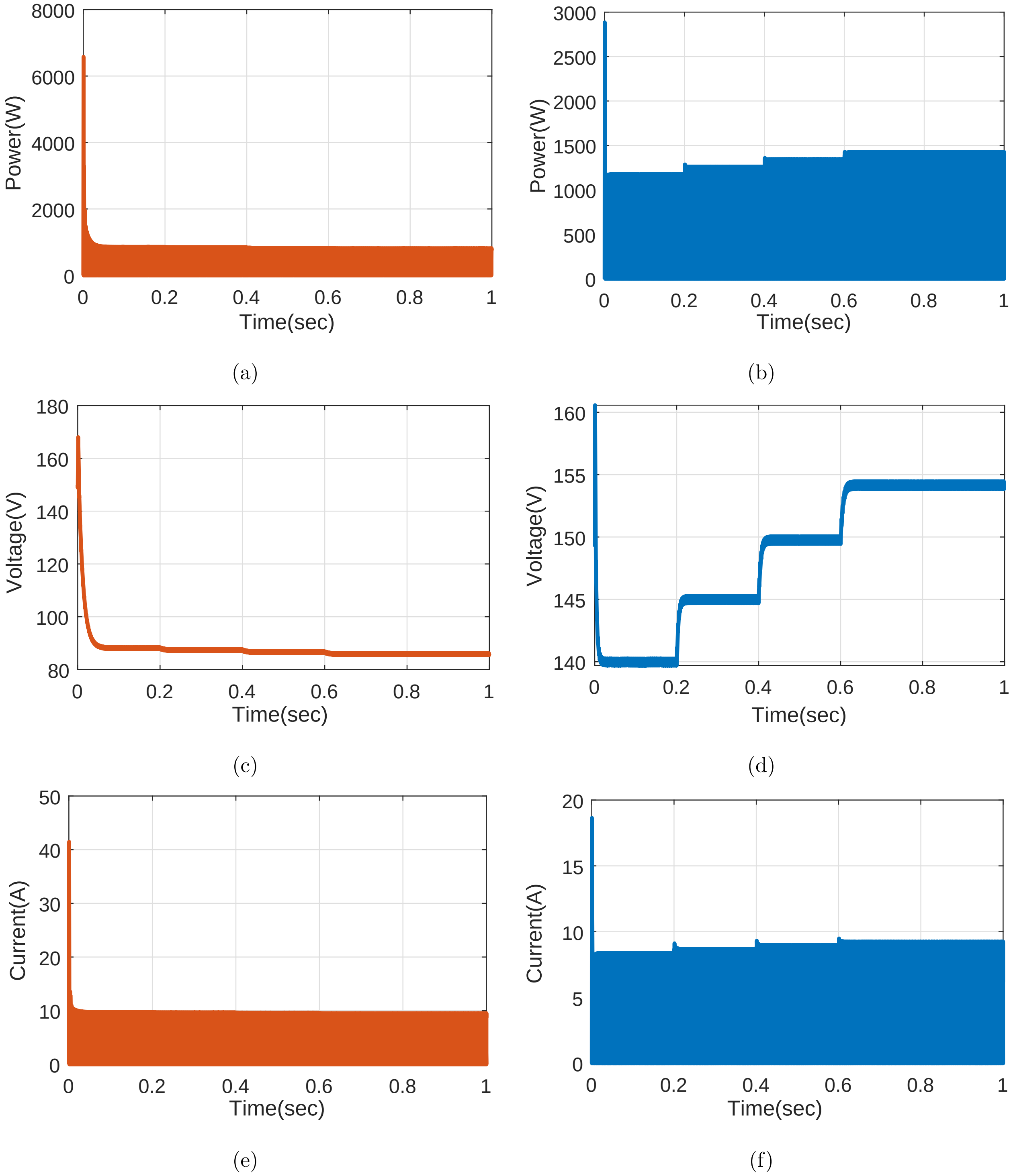


Figure 5.11: (a) Boost converter power with STC (coral colour), (b) Boost converter power with P&O (blue colour), (c) Boost converter voltage with STC (coral colour), (d) Boost converter voltage with P&O (blue colour), (e) Boost converter current with STC (coral colour), (f) Boost converter current (coral colour) with P&O (blue colour).

Additionally, the P&O method exhibits significant overshoot initially and subsequently settles at a steady state point with considerable perturbation, which constitutes the primary drawback of P&O. The STC method addresses this concern.

In Fig. 5.11, the power, voltage, and current of the boost converter are presented for two control methods, namely, STC and P&O. The measurements were obtained under constant irradiance (G = 1000 W/m^2) and varying temperatures (T = [45-35-25-15] $^{\circ}C$). Notably, the results indicate that the proposed STC method exhibits superior performance compared to the P&O method, as it eliminates overshoot and transient effects whenever sudden change in temperature. Additionally, the STC approach demonstrates a remarkably smooth curve, contributing to enhanced efficiency and addressing the limitations observed in the P&O method.

Based on simulation results, it may be concluded that the proposed STC approach works well under varying irradiance and temperature conditions, is highly precise, simple to use, and is more stable than the P&O method. According to the simulation results, it is evident that higher MPP power levels lead to an increase in the battery charging current. This higher charging current results in a prompt increase in the State of Charge (SoC) of the battery, leading to a faster charging process. As MPP power goes low based on temperature and irradiance, the battery charging current goes low, slowing the charging of the battery. Accurate and fast MPPT tracking will help in utilizing the maximum available solar panel output based on the locality and climate and charge the battery at the highest available and possible value of power.

5.6.3 Performance Benchmarking of S2V Strategies:

A comprehensive evaluation of the proposed Solar-to-Vehicle (S2V) charging strategy requires benchmarking against existing techniques in terms of efficiency, tracking speed, and stability under varying solar irradiance conditions. Below, the key performance metrics and compare the proposed Super-Twisting Controller (STC) with conventional MPPT approaches:

1. **Efficiency:** Efficiency is a critical metric that defines how effectively the MPPT algorithm extracts maximum power from the photovoltaic (PV) source.

Proposed STC MPPT: Achieves high tracking efficiency (¿98%) by reducing steady-state oscillations near the MPP.

P&O MPPT: Exhibits lower efficiency (typically 90–95%) due to continuous oscillations around the MPP.

Incremental Conductance (INC) MPPT: Provides slightly better efficiency than P&O but suffers under rapidly changing irradiance conditions.

Tracking Speed: Tracking speed refers to how quickly the MPPT algorithm adapts to changes in solar irradiance and finds the new MPP. It is crucial for maintaining stable power delivery in dynamic environmental conditions.

Proposed STC MPPT: Due to its fast convergence property, STC can track MPP within a few milliseconds, significantly reducing power loss during transient irradiance changes. P&O MPPT requires multiple iterations to locate the new MPP, making it slower (response time in the range of seconds).

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Proposed STC MPPT: Due to its fast convergence property, STC can track MPP within a few milliseconds, significantly reducing power loss during transient irradiance changes.

P&O MPPT: Requires multiple iterations to locate the new MPP, making it slower (response time in the range of seconds).

INC MPPT: Faster than P&O but still slower than STC due to increased computational complexity.

Stability Under Varying Solar Irradiance: The robustness of MPPT strategies is tested by subjecting them to fluctuating solar irradiance, which can cause voltage and current oscillations. Stability is assessed based on the ability of the MPPT algorithm to minimize overshoot, prevent voltage ripple, and ensure smooth convergence. Proposed STC MPPT Exhibits superior stability due to its inherent robustness against system uncertainties and parameter variations. The super-twisting control effectively mitigates chattering effects and provides smooth convergence to the MPP.

P&O and INC MPPT: Susceptible to fluctuations, especially under partial

shading or sudden irradiance variations, leading to voltage ripples and instability. The performance benchmarking results indicate that the Super-Twisting Controller (STC) MPPT out performs conventional P&O and INC methods in terms of efficiency, tracking speed, and stability. By reducing steady-state oscillations, improving transient response, and ensuring robustness under dynamic solar conditions, STC proves to be a promising candidate for real-time S2V charging applications.
Grid Integration Challenges: Integrating an S2V charging system with the existing power grid infrastructure presents several technical challenges: (i) Power Quality Issues: The injection of solar power into the grid may introduce harmonic distortions, voltage fluctuations, and reactive power imbalances. The use of active power filters and power factor correction circuits can mitigate these disturbances.
(ii) Bidirectional Power Flow Constraints: Enabling bidirectional energy exchange between the grid and EVs requires advanced power converters and a smart grid interface. Implementation of bidirectional inverters with grid synchronization capabilities ensures smooth energy transfer while maintaining grid stability.
(iii) Intermittency of Solar Power: Variability in solar irradiance leads to fluctuations in charging power, affecting grid stability. Energy storage integration (battery banks or supercapacitors) can smooth power fluctuations and improve grid reliability.

5.6.4 Hardware Implementation Considerations

Realizing an efficient and reliable S2V system requires careful selection of converter topology, thermal management solutions, and real-time control strategies:

The choice of DC-DC converters significantly impacts system efficiency and performance. A high-gain bidirectional converter with multi-phase interleaved topology can improve power density and reduce losses.
Thermal Management: High-power converters generate significant heat, impacting system reliability and efficiency. Implementation of liquid cooling systems or heat sinks with forced air cooling ensures effective thermal dissipation.
Real-time Control Feasibility: Precise MPPT control requires high-speed dig-

ital processing to adapt to changing solar conditions. Utilizing FPGA-based or DSP-based controllers can enhance computational efficiency and real-time tracking capabilities.

Regulatory and Safety Aspects: The deployment of grid-connected S2V charging systems must adhere to international regulations and safety standards: Grid Compliance Standards: Systems must comply with IEEE 1547 and IEC 61850 standards for grid-connected power electronics. Safety Concerns: Electrical isolation, grounding, and overcurrent protection are essential for safe operation. The use of galvanic isolation transformers and residual current protection devices (RCDs) enhances system safety.
Cybersecurity and Smart Grid Integration: The integration of S2V systems with smart grids introduces cybersecurity risks. Implementing secure communication protocols integrity and system protection.

5.7 Summary

This chapter concentrated on using the Super Twisting Controller (STC) in Solar-to-Vehicle (S2V) applications as a Maximum Power Point Tracking (MPPT) method for photovoltaic (PV) systems. The aim of this study was to explore how the STC can improve capturing energy efficiency while allowing the smooth charging of electric vehicles (EVs) using harmless solar energy. It evaluated the conventional Perturb and Observe (P&O) method and the STC-based MPPT. The STC method performed better than the P&O methodology in terms of tracking accuracy, response time, and stability throughout a range of environmental conditions, according to simulation findings from MATLAB/Simulink. This recent development depends on optimizing EV battery charging processes and increasing solar panel output. Additionally, the chapter discussed the role of a boost converter in stepping up the voltage from the PV panels to a level suitable for charging EV batteries. The boost converter, consisting of essential components such as an inductor, MOSFET switch, diode, and capacitor, is critical in ensuring efficient energy transfer. Future work could explore the effectiveness of the STC method in other renewable energy contexts and the optimization of its control parameters for varied operational scenarios. This chapter underscores the STC algorithm's promise as a robust solution for enhancing energy efficiency in renewable energy applications, contributing to sustainable transportation and clean energy initiatives.