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Integration of Solar Panel and KY Converter for Sustainable Electric Vehicle Charging Application

Mr. Raviraj B. Adlinge[1], Mr. Anand B. Kumbhar[2], Dr. Swapnil M. Hirikude[3], Mrs. Deshmukh Shubhangi C[4]
[1]Postgraduate Student (M. Tech), Department of Electrical Engineering, Sanjay Ghodawat University, Atigre, Maharashtra, India.
[2]Assistant Professor, Department of Electrical Engineering, Sanjay Ghodawat University, Atigre, Maharashtra, India.
[3]HOD & Assistant Professor, Electronics and Communication Engineering, Sanjay Ghodawat University, Atigre, Maharashtra, India.
[4]Assistant Professor, Electronics and Communication Engineering, Sanjay Ghodawat University, Atigre, Maharashtra, India.
Emails: *ravirajadlinge94@gmail.com[1], anand.kumbhar@sanjayghodawatuniversity.ac.in[2], hod.ece@sanjayghodawatuniversity.ac.in[3], shubhangi.deshmukh@sanjayghodawatuniversity.ac.in[4]*

Abstract
As the shift toward eco-friendly transportation accelerates, there is a growing demand for integrating renewable energy sources into electric vehicle (EV) charging systems. This study proposes a solar-powered EV charging framework that employs an enhanced KY converter to efficiently manage the intermittent nature of photovoltaic (PV) energy. Its notable advantages—such as low voltage ripple, rapid transient response, and high operational efficiency—make it more effective than traditional DC-DC converters in renewable energy applications.To further strengthen voltage regulation, a proportional-integral (PI) controller is implemented, allowing real-time tuning of the converter's duty cycle in response to changes in solar irradiance. This feedback-based control system ensures consistent DC link voltage and enhances the overall reliability and responsiveness of the setup. MATLAB Simulation analyses validate that the system effectively maintains voltage stability and promotes efficient energy utilization under dynamic environmental conditions.This approach offers a practical and sustainable pathway for clean energy integration into the transportation sector. The combination of solar PV technology with KY converter-based power control demonstrates a scalable model for future smart EV charging infrastructure aligned with global sustainability goals.

Keywords: *KY Converter; Electric Vehicles; MATLAB Simulation; Renewable Energy Integration; Proportional Integral (PI) Control; Photovoltaic (PV) System.*

1. Introduction
The global shift toward sustainable energy and transportation has made electric vehicles (EVs) a vital component in reducing greenhouse gas emissions and fossil fuel dependency. Unlike traditional vehicles powered by internal combustion engines, EVs rely on electric motors and rechargeable batteries, offering cleaner and more efficient transportation solutions (1, 2). With the rapid growth of the EV market, there is an increasing need for reliable, efficient, and widely accessible charging infrastructure (3, 4) EV battery charging typically occurs across three standardized levels: Level 1 uses standard 120V AC outlets and offers the slowest charging rate, making it suitable for overnight home charging. Level 2, operating at 240V, provides faster charging and is common in residential and commercial environments. DC Fast Charging (Level 3) uses high-power direct current to rapidly recharge vehicles, often restoring 80% of battery capacity in under an hour (5, 6). To address these concerns, integrating renewable energy sources, particularly photovoltaic (PV) solar energy, with EV charging systems presents a promising solution. PV

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systems convert sunlight into electricity and can be deployed on rooftops, carports, or open land, providing decentralized, emissions-free energy for vehicle charging (7, 8). Solar-powered EV charging not only reduces dependency on grid electricity but also enhances energy sustainability by minimizing lifecycle emissions associated with EV operation (9, 10). However, the inherent variability of solar energy, due to fluctuating irradiance, temperature, and shading, results in inconsistent voltage and current outputs from PV panels (11). This variability poses challenges for directly charging EV batteries, which require stable and controlled voltage and current levels to ensure battery safety, lifespan, and efficiency. To overcome this, DC-DC converters are essential in PV charging systems to regulate and condition the output before supplying it to the battery (12). DC-DC converters also facilitate maximum power point tracking (MPPT), a critical technique that ensures PV panels operate at their most efficient point under changing environmental conditions (13, 14). By dynamically adjusting the operating voltage of the PV array, MPPT enables maximum energy harvest. Common converter topologies used in such applications include buck, boost, and buck-boost converters. While effective, these traditional converters often suffer from performance limitations such as pulsating input/output currents, higher voltage ripples, and reduced efficiency under varying load conditions (15). In contrast, the KY converter presents a more advanced topology that offers continuous input and output currents, lower voltage ripple, and better voltage gain than conventional boost converters. These characteristics make it highly suitable for applications involving renewable energy and battery storage systems. The KY converter is particularly effective in scenarios requiring a large voltage boost from low-voltage sources like PV arrays while maintaining efficiency and minimizing electrical stress (16, 17, 18). Further enhancement of system performance can be achieved by incorporating a proportional-integral (PI) controller into the KY converter. The PI controller monitors the DC output voltage and dynamically adjusts the duty cycle of the converter, maintaining output stability even as the solar input fluctuates throughout the day this feedback control loop improves system responsiveness and voltage regulation, which are critical for safe and efficient EV charging (19). This study introduces a solar-powered electric vehicle (EV) charging system that incorporates a KY converter controlled by a proportional-integral (PI) regulator, with the goal of enhancing energy conversion efficiency, voltage consistency, and system dependability. The proposed setup is designed and simulated using MATLAB/Simulink to assess its performance under different solar irradiance levels and load variations. Key performance indicators such as voltage ripple, dynamic response, output voltage regulation, and overall converter efficiency are thoroughly examined. The simulation outcomes confirm that the KY converter is capable of delivering a stable and clean DC output, making it well-suited for EV charging applications. In conclusion, the research demonstrates a robust and energy-efficient approach to EV charging through solar integration, highlighting the KY converter's effectiveness in supporting the advancement of sustainable and practical electric transportation systems [1-3].

1.1 Theoretical Background

The KY converter is a type of DC-DC power converter designed to increase input voltage to a higher output level. Introduced in 2005, it has gained significant attention due to its performance benefits over conventional boost converters. A notable feature of the KY converter is its rapid transient response, which allows it to adapt swiftly to sudden changes in load conditions—an essential trait for applications with frequent load variations. Additionally, the converter delivers a low output voltage ripple because it produces a continuous, non-pulsating output current. This results in reduced stress on the output capacitor and leads to a more stable voltage output. Another strength of the KY converter lies in its higher efficiency and broader operational voltage range, both at the input and output. These qualities make it highly adaptable and suitable for various modern applications, including renewable energy systems like solar and wind power, electric and hybrid vehicles, portable battery-operated equipment, industrial control systems, and power management in electronic devices [4-9].

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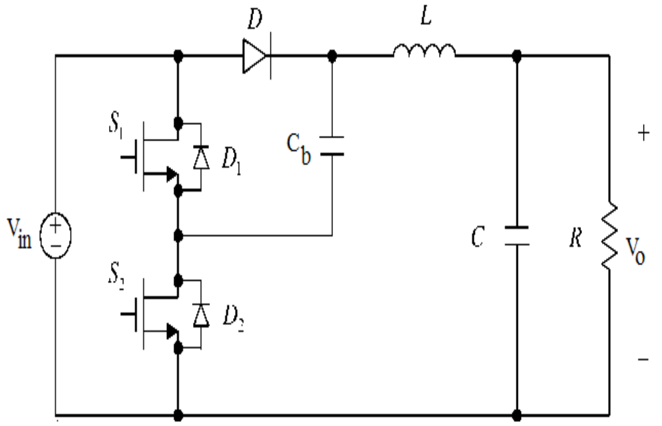

Figure 1 Basic KY Converter

Figure 1 shows the KY boost converter. It is constructed with two semiconductors switching devices S_1 and S_2, a diode D, energy transferring capacitor C_b, output inductor L, and the output capacitor C. The working of KY converter can be explained in two modes as follows [10]:

Mode-1: S_1 = ON, S_2 = OFF

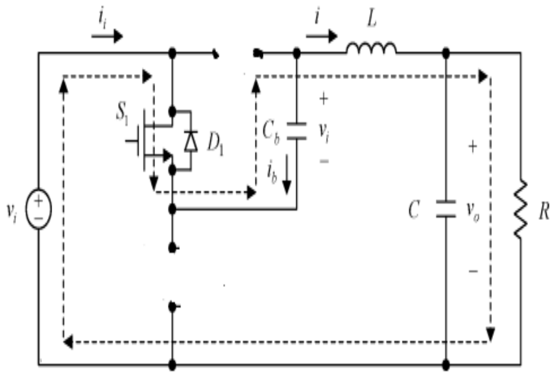

Figure 2 KY Converter Mode-1 Configuration

Figure 2, In this mode, the inductor L is magnetized as the voltage across inductor L is,

$$V_L = V_{in} + V_c - V_O \quad .....1$$

where:

- V_L= Voltage across inductor
- V_{in}=Input Voltage
- V_c = Voltage across capacitor
- V_O = Output Voltage

Neglecting voltage drop across diode D,

$$V_C = V_{in} \quad ......2$$

$$\therefore\ V_L = 2V_{in} - V_O \quad ......3$$

Here the capacitor Cb is discharged

Mode-2: S_1 = OFF, S_2 = ON

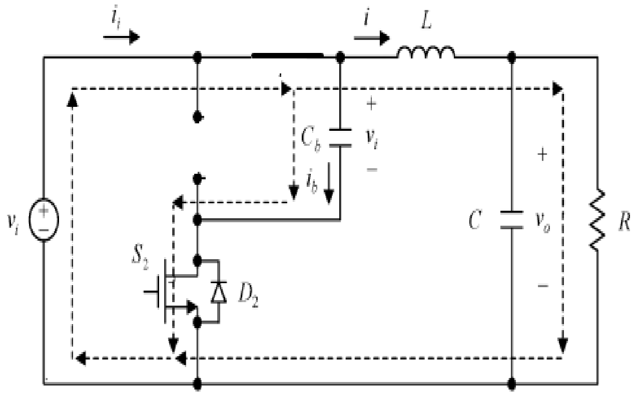

Figure 3 KY Converter Mode-2 Configuration

In this mode, the inductor L is demagnetized as the voltage across inductor is,

$$\therefore\ V_L = V_{in} - V_O \quad ....4$$

Here the capacitor Cb is quickly charged to the input voltage level in very short interval.

The voltage gain is thus given as

$$A = \frac{V_O}{V_{in}} = 1 + D \quad ....5$$

where:

- A= Voltage gain of converter
- D = Duty cycle

1.2 Proposed System

Figure 2 illustrates the block diagram of the proposed photovoltaic (PV) system integrated with a KY converter. In this setup, both the PV panel output voltage and the load voltage are continuously monitored and fed back to the control unit. Based on the difference between the reference voltage and the actual output, the controller adjusts the pulse-width modulation (PWM) signals accordingly. These PWM signals help regulate the converter's operation to maintain a stable output. To ensure safe and effective communication between the low-voltage control circuitry and the high-voltage power stage of the converter, a driver circuit is incorporated, providing the necessary electrical isolation. The design of the KY converter will be based on the specifications of the photovoltaic (PV) panel and the connected load. A proportional-integral (PI) controller is proposed to maintain a stable output voltage from the converter. This controller functions by adjusting the duty cycle of the PWM signals in response to voltage deviations, thereby ensuring effective voltage regulation under varying operating conditions [11-14].

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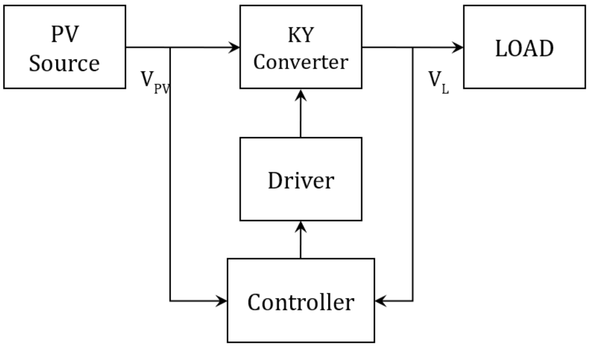

Figure 4 Block Diagram of Proposed System

2. Design of KY Converter

For case study, a KY converter for EV charging application is designed for the specifications as mentioned in Table 1.

Table 1 System Specifications

Particulars	Specification
Input Voltage (Vin)	12V
Output Voltage (Vo)	20V
Frequency	10Khz
PV Panel	12V, 50 W

The output current of KY converter

$$I_o = \frac{P_O}{V_O} = \frac{50}{20} = 2.5A \quad .....6$$

where:

- Output current, I_o =2.5A
- Output power, P_O=50W
- Output Voltage, $V_O = 20V$

The input current of KY converter is,

$$I_{in} = \frac{P_{in}}{V_{in}} = \frac{50}{12} = 4.16A \ .....7$$

where:

- Input current, I_{in}=4.16A.
- Input power, P_{in}=50 W.
- Input voltage, V_{in}= 12V.

The voltage gain is

$$A = \frac{V_O}{V_{in}} = \frac{20}{12} = 1.66 \quad ......8$$

Therefore, the duty cycle of converter is calculated as,

$$A = 1 + D \quad ......9$$

$$\therefore \boldsymbol{D = 0.66}$$

a) Inductor Design

For calculating inductor value, the voltage across inductor is considered.

By KVL, the voltage across inductor is,

$$V_L = 2\,V_{in} - V_o = 4V \ ....10$$

The basic equation of inductor is,

$$V_L = L\frac{di}{dt} \quad ....11$$

$$\therefore L = V_L\frac{dt}{di}$$

Here, the interval dt is,

$$dt = \frac{D}{f} \quad ....12$$

The current di is ripple current of the inductor. It is assumed that the inductor ripple current is 30%

The inductor current is,

$$I_L = 2\,I_{in} = 2 * 4.16 = 8.32\ A \ .....13$$

$$\therefore di = 0.40 * 8.32 = 3.33\ A \ .....14$$

Substituting these values in the equation of inductance,

$$L = V_L\frac{dt}{di} = V_L\frac{D}{f.di} = 4\frac{0.66}{10000 \times 3.33} = 79\mu H \quad ....15$$

where:

- Inductor voltage, V_L=4V
- Duty cycle, D=0.66
- Switching frequency f= 10KHz
- Ripple current, di=3.33A
- **Inductance, L=$\boldsymbol{79\mu H}$**

b) Energy Transferring Capacitor Design

The current through capacitor C_b is,

$$I = C_b\frac{dV}{dt}$$

$$C_b = I\frac{dt}{dV} = I_{in}\frac{D}{f\ dV} \quad ....16$$

Assuming dV, the ripple voltage across capacitor to be 2% of the source voltage,

$$dV = 0.01 \times 12 = 0.24 \quad ......17$$

$$C_b = I_{in}\frac{D}{f\ dV} = 4.16\frac{0.66}{10000 \times 0.24} = 1100\ \mu F \quad ....18$$

where:

- Input current , I_{in}=4.16A.
- Duty cycle, D=0.66
- Switching frequency f= 10KHz

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- Ripple voltage, dv=0.24V
- **Energy transferring Capacitor, C_b=1100 μF**

c) Output Capacitor Design

For output capacitor,

$$I = C_o \frac{dV}{dt} \quad ....19$$

Assuming dV, the ripple voltage across capacitor to be 1% of the output voltage,

$$dV = 0.01 \times 20 = 0.2$$

$$C_o = I_{out} \frac{D}{f\ dV} = 2.5 \frac{0.66}{10000 \times 0.2} = 825\ \mu F \quad ....20$$

where:

- Output current , I_{out}=2.5A.
- Duty cycle, D=0.66
- Switching frequency f= 10KHz
- Ripple voltage, dv=0.20V
- **Output Capacitor, C_o=825 μF**

3. MATLAB Simulation and Results

Figure 3 presents the MATLAB Simulink model of a photovoltaic (PV)-based electric vehicle (EV) charging system incorporating a KY converter. In this configuration, a PV array serves as the primary energy source. The KY converter operates in boost mode to elevate the input voltage to a suitable level for charging. The system is designed to charge an 18V EV battery, so the KY converter is configured to supply a slightly higher voltage—set at 20V—to ensure efficient charging.To achieve this, the converter's output voltage is regulated using a proportional-integral (PI) controller. The controller receives the error signal, calculated as the difference between the actual output voltage and the reference value of 20V. Based on this error, the PI controller adjusts the duty cycle, which is then passed to the PWM generator. The PWM generator produces the necessary gate signals to control the KY converter. As a result, the converter consistently delivers a 20V output to charge the EV battery effectively.

3.1 PV Array Performance

Figure 4 presents the simulated response of the photovoltaic (PV) system under varying irradiance conditions. The top plot captures a sudden drop in solar irradiance—from approximately 1000 lux to 500 lux—occurring at 0.06 seconds. This step change emulates real-life scenarios such as passing clouds or partial shading. The middle graph illustrates the PV voltage (V_{PV}), which remains steady around 15V before the drop and slightly decreases to approximately 13–14V afterward. This modest reduction demonstrates the system's voltage stability despite a significant decline in irradiance. The bottom plot shows the PV current (Ipv), which initially experiences startup transients but stabilizes at around 8A before the irradiance change. These waveforms reflect the system's capability to adapt quickly to dynamic environmental conditions [15-19].

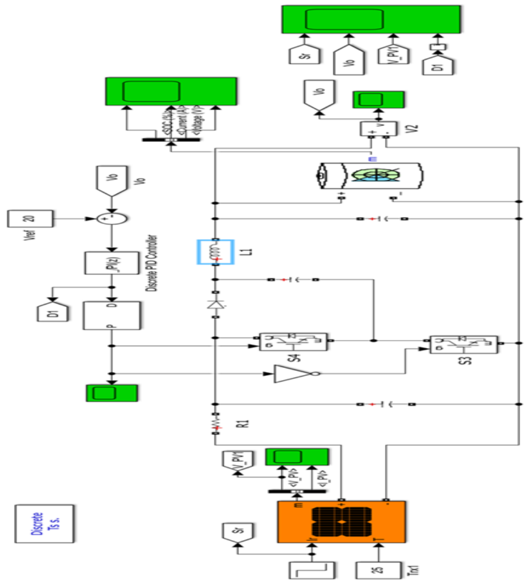

Figure 5 MATLAB Model of PV based EV Charger with KY Converter

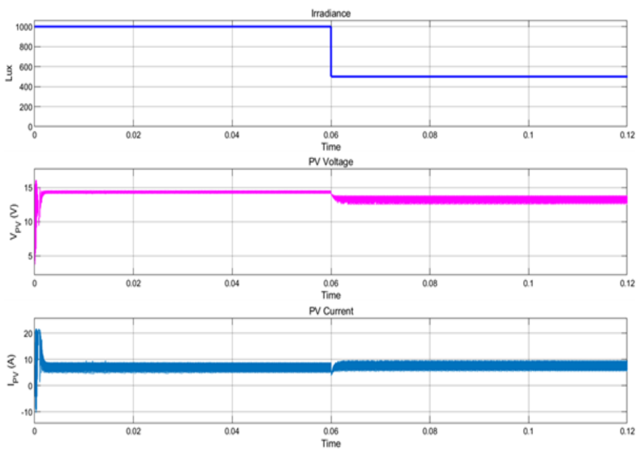

Figure 6 Waveform of Irradiance, PV Voltage (V_{PV}), PV Current (Ipv).

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3.2 KY Converter Performance

Figure 5 displays the simulation waveforms of irradiance, KY converter output voltage, and duty cycle variation. As the incident solar radiation decreases, a slight drop in the PV voltage is observed. In response, the closed-loop control system dynamically adjusts by increasing the duty cycle. This corrective action ensures that the KY converter maintains a stable output voltage, despite fluctuations in the input. As a result, the system demonstrates its effectiveness in delivering a constant voltage, making it well-suited for consistent battery charging under varying solar conditions.

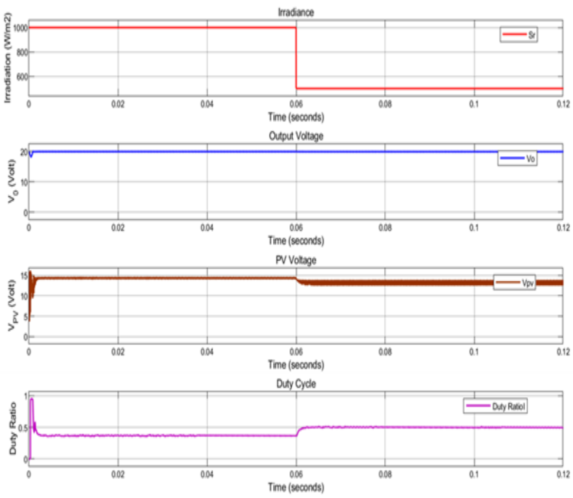

Figure 7 **Irradiance, KY Converter output voltage, PV Voltage and Duty Cycle**

3.3 EV Battery Profile

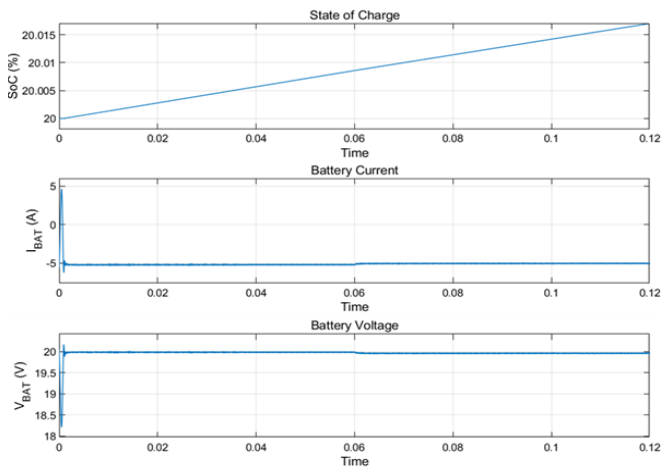

Figure 8 **Battery SOC, Current, Voltage.**

Figure 6 illustrates the battery system's voltage, current, and state of charge (SOC) over the simulation period. The continuous rise in SOC confirms that the battery is undergoing a charging process. Around the time instant of 0.06 seconds, a minor dip in charging current is observed, which corresponds to a reduction in solar irradiance. Despite this brief fluctuation, the system continues to charge the battery effectively, shown in Figure 7 & 8.

Conclusion

The implementation of a photovoltaic (PV)-based electric vehicle (EV) charging infrastructure incorporating an enhanced KY converter presents a significant advancement in the integration of renewable energy within the transportation sector. The KY converter, capable of operating in step-up mode, effectively manages the variable nature of solar output, ensuring a regulated and continuous power supply to the EV battery. Owing to its low output voltage ripple, fast dynamic response, and superior efficiency, the KY converter offers distinct advantages over conventional DC-DC converter topologies. To further reinforce voltage regulation and system reliability, a proportional-integral (PI) controller is integrated, enabling dynamic control of the converter's duty cycle in response to fluctuating solar irradiance. This closed-loop configuration maintains a stable DC-link voltage, supporting consistent charging performance under diverse environmental conditions. The proposed system not only promotes the utilization of clean energy but also reduces fossil fuel dependence, thereby aiding efforts to minimize greenhouse gas emissions. This work highlights the potential of combining PV energy with intelligent power electronic converters to develop scalable, efficient, and environmentally responsible EV charging solutions—contributing meaningfully to global sustainability objectives in energy and transportation.

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