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Dragonfly Optimized PI Controlled SEPIC Converter for Efficient Solar-Powered EV Charging Applications

D. Lakshmi[3], E. Immanuvel Bright[4]

[3]Department of Electrical and Electronic Engineering, AMET University, Chennai, Tamil Nadu, India.
[4]Assistant Professor, Department of Electrical and Electronic Engineering,
Erode Sengunthar Engineering College, Perundurai, Erode, Tamil Nadu, India - 638057.

ABSTRACT: The attempt to limit the release of greenhouse gasses that cause global warming and to protect fossil fuels, which are becoming rarer, has led to a sharp growth in development of renewable energy installations in recent years. As the number of electric vehicles (EVs) rises, infrastructure for charging them must be improved and extended. Hence, charging stations are required for long distance travel where energy obtained from renewable energy sources(RESs), since energy stored in batteries of vehicles are not sufficient for long distance driving. Therefore, to overcome this challenges EV charging station which is equipped with RES, converter topology and optimization technique is proposed. In this paper, energy is received from solar Photovoltaic (PV) system and fed into converter section which improves the DC voltage attained from PV system. Single-ended primary inductance converter (SEPIC) is used, in which voltage fluctuation from converter requires optimization. This optimization is performed using Dragonfly optimized Proportional-Integral controller (DOA-PI), which in turn aids in faster convergence of algorithm iterations and controls DC link supply with constant power given to EV load. Using MATLAB simulation software, experiment is executed and respective outputs are obtained with efficiency of 91.2% and voltage gain of 1:8.

Keywords: Electric vehicle, Proportional Integral controller, Photovoltaic system, SEPIC converter, Dragonfly algorithm, MATLAB software.

1. Introduction

Depletion of fossil fuel resources and demand for clean environment and sustainable transportation accelerate the adoption of EVs that are charged using RES including PV systems and hydrogen fuel cells [1,2]. RES produces very low DC voltage, because of its intermittent condition in place of producing high voltage for charging motor drives, battery charging system and EV powertrains. Hence, to overcome this voltage issues, high gain DC-DC converters are required for RE based EV system [3]. In [4] non-isolated quasi-Z-source(qZ-S) dc to dc converter is introduced that aids in high voltage gain based on duty cycle and minimum ripples in input current. Although converter suffers from inductance leakage effects and degradation of efficiency at high gain. In [5], a converter approach with active switched-inductors (ASL) and switched capacitor cells (SCC) is proposed, that produces high step-up value at low duty cycle with low component count and minimal switch stress. Although this converter has limited high-power scalability and it suffers from conduction losses. In [6], battery charger with dual stage is introduced using an interleaved buck-boost converter, that aids in improving input current and power factor. Although the converters reliability rises and cost of the model is reduced, it has switching and current-sharing issues. Hence, SEPIC converter

[7] is proposed in this work, to overcome this disadvantage in baseline models. Using Genetic Algorithm (GA) [8], Model predictive Control (MPC) optimization is executed and real-time current and voltage values from PV panel is used to evaluate GA fitness function and control parameter that are optimized are send to controller. Despite of its advantages, controller performance depends on GA parameters and take long duration for optimization. Hence, DOA-PI controller approach is employed in this work, that aids in handling different conditions such as single-multi objective problem.

2. Recent Works

Farha Khan et al [2025] [9] have proposed a hybrid model of quadratic boost DC-DC converter used in EV charging which produces high voltage gain, lower switching losses with improved efficiency. To extract solar power, a feed forward neural network based-MPPT algorithm is implemented and Controller Hardware-in-the Loop (CHIL) used for implementing real-time data and simulations. Although efficiency of this work is 95.6%, prototype of converter is simulated under 100W rating due to its requirement on safety and laboratory constraints.

Amritanshu Ruhela et al [2025] [10] have proposed a innovative model considering Boost-SEPIC-based three-port converter (TPC), which extracts energy from PV, stores in a battery and delivers consistent power to load. To enable closed loop operation, a single control strategy is used. To track maximum power point, front-end boost converter is employed. Although the proposed work has low current ripples and load voltage control, drawbacks such as limited PV installation, dependence on solar irradiation and control complexity.

Ling Qin et al [2023] [11] have presented a novel work for standalone PV-based electric vehicle charging using interleaved high-gain boost converter, in which an additional input inductor and switch is incorporated by splitting step-up network. Using this converter, continuous input and output current is analysed which reduces need for filter capacitance. To demonstrate correctness of theoretical analysis, converter topology is validated using 500-W/50-kHz prototype. The drawbacks are PV intermittency, scalability issue and capacitor voltage-balancing issues.

Vandana Jain et al [2023][12] have proposed a charging station for EVs interfaced with three-phase grid, in which reference grid currents synchronize with phase voltages at PCC (Point of Common coupling). Although it achieves reactive power compensation, the system requires high investment initially, issues in grid synchronization and it does not has battery storage capabilities.

Ankit Kumar Singh [2025][13] have proposed a interleaved Buck converter (IBC) that is interfaced with solar panel, in which IBC is combination of traction converter switches and motor windings. Copper losses and on-state losses in switches are reduced by using IBC. Despite of its advantages, system suffers from conversion losses, challenges in thermal management and it depends on environmental conditions.

The main benefactions of this work are listed in the following:

- Incorporating PV system as essential power source because of its non-pollutant nature, sustainability and easily available energy source.
- To improve performance of charging system and determining controller parameters, DOA-PI controller is employed.
- To provide step-up and step-down voltage conversion, SEPIC converter is employed that regulates varying output of PV system.

Implementation is performed using MATLAB Simulink software and proposed work is explained in the following section.

3. Proposed Work Explanation

In this section, proposed system for solar powered EV charging is explained. The schematic diagram consists PV system, SEPIC converter, EV load, PWM generator and DOA-PI controller as depicted in Figure 1.

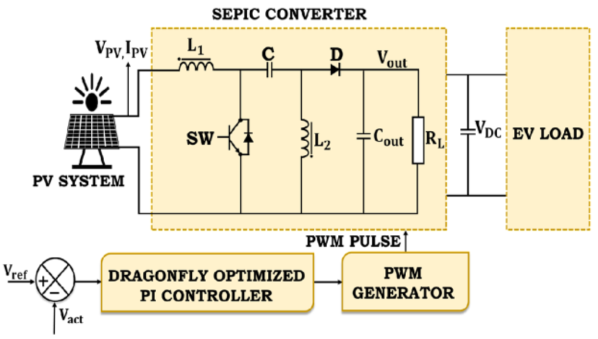

Figure 1: *Block diagram of EV charging system*

3.1 Solar PV cell

The schematic diagram of PV cell with single diode is shown in Figure 2. Ambient temperature condition and radiation incident angle of solar panel are considered for PV parameter modelling. Singel diode is used in PV panel construction, since it has simple design and aids in analysing PV panel performance.

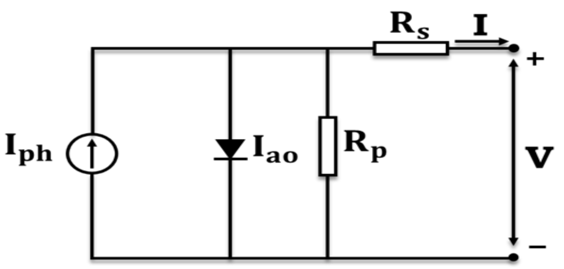

Figure 2: *Electrical circuit of PV cell*

Equation (1) describes relationship between voltage and current of PV cell,

$$I = I_{Ph} - I_S[exp\left(\frac{V+IR_S}{nV_T}\right) - 1] \quad (1)$$

Where I_S is reverse saturation current of PV cell, I_{Ph} denotes PV current, Thermal voltage is denoted as V_T in which V is output voltage of solar cell model in series connection. Equivalent series and parallel connection of cell is denoted as R_S. $V_T = k * T * a/q$ connected with n series cells where 'k' is Boltzmann constant (1.3806503×10^(-23) J/K). 'a' indicates ideality constant of Diode, 'T' denotes p-n junction temperature and 'q' denotes charge of electron [1.60217646×10^(-19) C]. Since loss of power from PV panel is dissipated as heat, which in turn reduces output power of panel. Hence, a converter approach is incorporated to improve low DC voltage of PV panel and it is explained in the following.

3.2 SEPIC converter

Using SEPIC converter, level of dc voltage obtained from panel is adjusted to attain constant voltage output, given to EV load. The circuit diagram for converter approach is depicted in Figure 3.

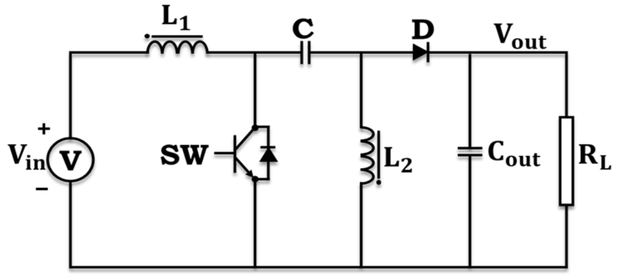

Figure 3: *SEPIC converter*

When the MOSFET is on or gate pulse is high in SEPIC converter, input voltage charges inductor 1 and capacitor 1gives charge to inductor 2.

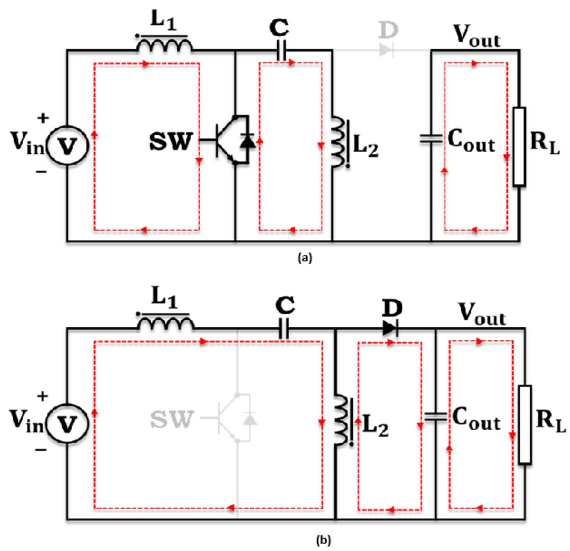

Figure 4: *Current flow during (a) Q1 on time (b) Q1 off time*

When diode is in off condition as shown in Figure 4(a), output is sustained with the help of capacitor 2. During Off condition of MOSFET or low pulse as shown in Figure 4(b), inductor output flows through diode to load, which in turn charges capacitors. Higher percentage of duty cycle leads to higher output, although if the pulse last for long duration, it will damage capacitors from charging and converter fails.

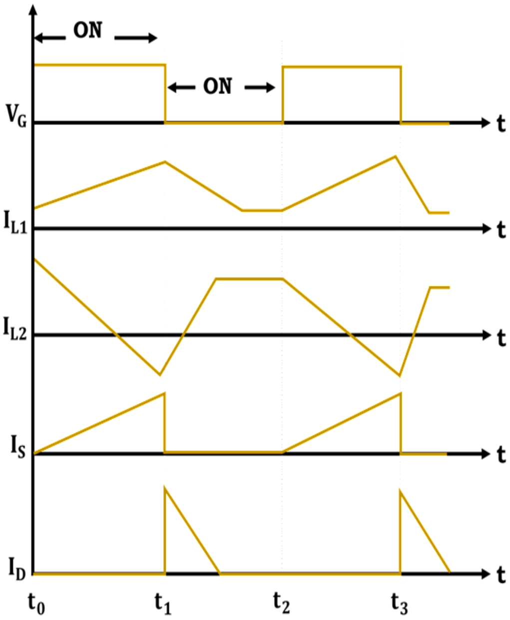

Figure 5: *SEPIC converter waveforms*

In a continuous conduction mode (CCM) of SEPIC converter, V_D is indicated as forward voltage drop of diode D1. Step-up and step-down of voltage by SEPIC converter is based on elements in circuit and duty cycle. Output of an SEPIC converter is given in equation (2) as follows,

$$V_0 = \frac{D*V_i}{1-D} \tag{2}$$

Losses due to parasitic elements like diode drop indicated as VD in circuit is given in equation (3),

$$V_0 + V_D = \frac{D*V_D}{1-D} \tag{3}$$

Equation (3) becomes,

$$D = \frac{V_o+V_D}{V_i+V_o+V_D} \tag{4}$$

With the minimum input voltage, duty cycle is obtained at maximum. Optimization of converter is required to lower fluctuations in voltage that is done using PI controller tuned DF algorithm, explained in the following.

3.3 DOA- PI controller

To address optimization issues such as single and multi-objective problems, a novel optimization methodology is developed named DOA which is created by Mirjalili in 2015. DA module is created from static and dynamic swarming technique, depending on stages of exploitation and exploration. Equation (5) states formula for evaluating separation,

$$H_i = -\sum_{j=1}^{N} (Y - Y_j) \tag{5}$$

Where Y indicates present individual position, N denotes neighbouring individual count and Y_j indicates position j on neighbour individual. Two vectors are calculated for updating position of dragonflies in exploration stage to evaluate their movements, (i) step (ΔY) and (ii) position(Y) vectors.

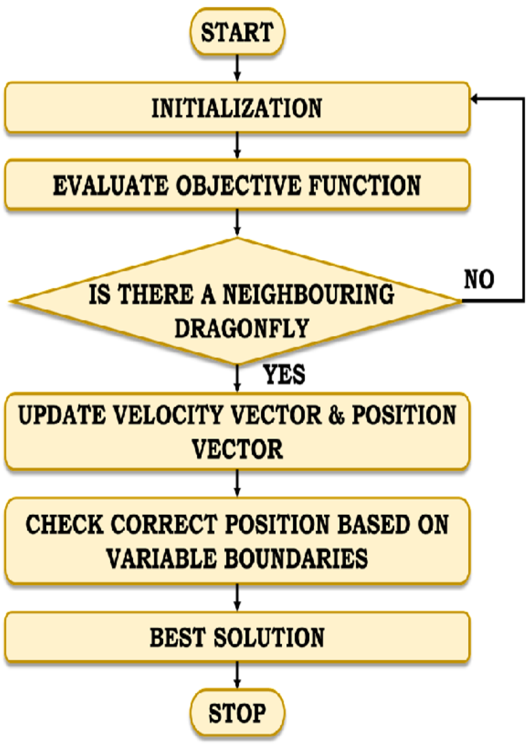

Figure 6: *Flowchart of DOA*

The direction of dragonfly movement is the step vector, which is given in Equation (6) in the following,

$$\Delta Y(t+1) = (pH_i + aB_i + cG_i + fF_i + eE_i) + w\Delta Y(t) \tag{6}$$

In equation (6), ith individual separation is denoted as H_i, weight of alignment is denoted as a, weight of separation is denoted as p, ith individual cohesion is denoted as G, food factor is denoted as f, food resource of ith individual is denoted as F_i, enemy factor is denoted as e, iteration counter is denoted as t, inertia weight is denotes as w and ith individual position of enemy is indicated as E_i. The position vector of dragonfly is evaluated with the Equation (7) as follows,

$$Y(t+1) = Y(t) + \Delta Y(t+1) \qquad (7)$$

Where t denotes current iteration.

4. Results and Discussion

To store the energy produced from RESs in a battery for charging EVs that are used for long distance travel, solar-powered EV charging is proposed. In this section, outcomes obtained to charge EV load, which is executed in MATLAB Simulink software is explained. Table 1 illustrate the parameters specified in the proposed work.

Table 1: *Parameters Specification*

Parameter	Description
Solar PV System	
Maximum Power(W)	240.5376
Short circuit Current(A)	8.32
Cells per module (Ncell)	60
Open circuit Voltage(V)	36.84
Series Connected module per string	4
Voltage at maximum power point (V)	30.72
Current at maximum power point (A)	7.83
Temperature coefficient of Voc(%/deg.C)	-0.359
Temperature coefficient of Isc(%/deg.C)	0.096995
SEPIC Converter	
Light-generated current IL (A)	8.3299
Dide saturation current IO (A)	2.8736e-10
Diode ideality factor	0.99259
Shunt resistance Rsh (ohms)	330.6558
Series resistance Rs (ohms)	0.19366

The solar panel waveforms are illustrated in Figure 6. From temperature waveform shown in Figure 7(a), it is observed that initially temperature is maintained at 25°C, after 0.3sec temperature raised to 35°C and it is gradually maintained constant throughout the system. In Figure 7(b), intensity waveform details that till 0.6sec, intensity is maintained at 800W/sq-m. After 0.6sec, intensity increased to 900W/sq-m and it is maintained constant throughout the system.

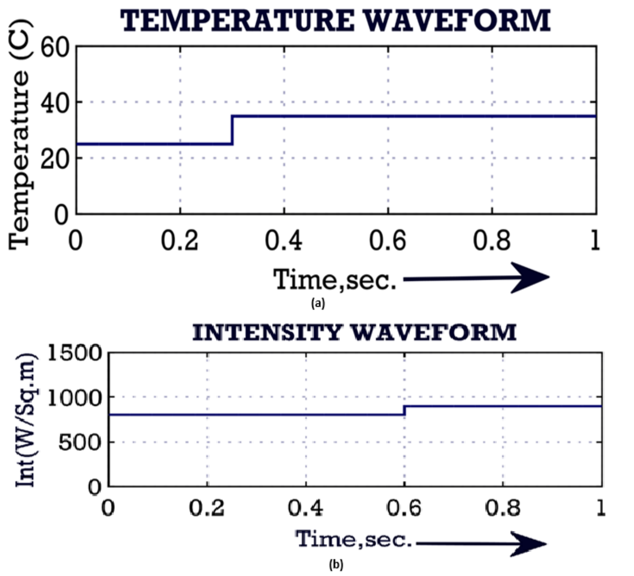

Figure 7: *PV panel Waveforms (a) Temperature waveform (b) Intensity waveform*

The input voltage and current waveforms of solar panel is shown in Figure 8. Initially voltage increases above 100V and gradual fluctuations occurs due to intermittent nature of RESs, voltage is steadily maintained after 0.6sec at 150V. In Figure 8(b), input current of panel is specified, that details about gradual increase of current till 40A, then it decreases and maintained constant at 20A with slight fluctuations.

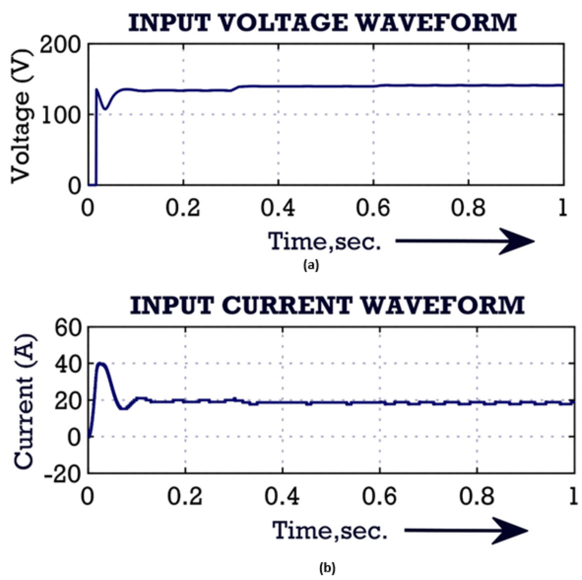

Figure 8: *Waveforms of PV panel (a) Input voltage (b) Input current*

Voltage and current waveforms of converter approach in output side is shown in Figure 9. Output volage of SEPIC converter is gradually increasing till 600V, then it decreases to 450V and with slight fluctuations voltage is maintained at 500V throughout the system. In Figure 9(b), current waveform for converter details that converter current gradually increases to 6A, then gradually decreases and it is maintained constant at 5A after 0.4sec with slight fluctuations.

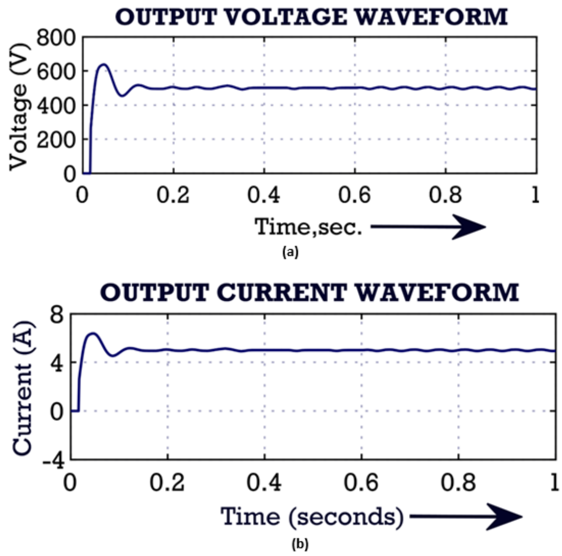

Figure 9: *Converter waveforms (a) Output voltage (b) Output current*

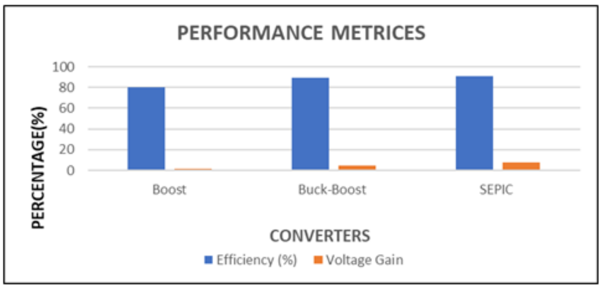

Figure 10: *Comparison on converter topologies*

The performance metrices are shown in Figure 10, comparing voltage gain and efficiency of converters such as Boost, Buck-Boost and SEPIC converter. It details that SEPIC converter performs with high efficiency of 91.2% and voltage gain of 8 than other conventional converters.

5. Conclusion

In this work, a EV charging topology is proposed that aids long distance travel easier by charging EVs with the use of RESs because of its non-pollutant nature. SEPIC Converter is employed to improve voltage obtained from panel because there will be fluctuations due to intermittent nature of sun. Due to its fast convergence better damping nature and fewer iterations required for execution, DF-based PI controller is deployed in this work. Optimization is required due to its voltage fluctuations occurs in converter section. Overall system is executed in MATLAB Simulink software and corresponding outcomes are obtained for panel and converter portion. The converter works efficiently with efficiency of 91.2% and voltage gain of 1:8 than other converters.

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