Optimizing Electric Vehicle Charging with Moth Flame Control Algorithm of Boost-KY Converter

Santosh D. Gadekar[1], M. Murali[2]
[1]Research Scholar, Faculty of Electrical Engineering, Medi-Caps University, Indore, MP, India
[2]Associate Professor, Department of Electrical Engineering at Medi-Caps University, Indore, MP, India

Abstract. Electric vehicles have assumed a prominent role in future transport system due to the diminishing availability and escalating costs of fossil fuels, coupled with growing concerns about the impact of global warming. The purpose of the work consists in addressing the pressing need for efficient and sustainable solutions in the realm of electric vehicles and renewable energy integration. The tasks solved in the article to achieve the given goal are the following: an improved Boost-KY converter has been introduced to counter the inherent limitation of low PV panel voltage output. This converter effectively mitigates voltage and current ripples, thereby ensuring a stable power supply for EV charging. Additionally, the Moth Flame Optimized Proportional Integral (MFO-PI) controller has been implemented to regulate converter operation, demonstrating exceptional proficiency in mitigating PV output unpredictability. MATLAB simulation is done to validate the proposed system's performance. The most important results are the achievement of impressive maximum efficiency of 96.21% and remarkably low Total Harmonic Distortion (THD) value of 1.04%. The system maintains consistent voltage and current levels for PV panels and EV battery, ensuring dependable energy supply. The significance of the results obtained consists in their potential to revolutionize the intersection of renewable energy integration, electric vehicle (EV) adoption, and sustainable transportation practices.The PV-based EV charging system not only reduces dependence on finite fossil fuel resources but also contributes to environmental preservation, aligning with global efforts to combat climate change. Furthermore, system adheres to stringent requirements of IEEE 519 standards, positioning it as a catalyst for the adoption of clean energy solutions within the future transport system.
Keywords: PV system, electric vehicle, improved Boost-KY converter, Moth Flame optimized PI controller.
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Optimizarea încărcării vehiculelor electrice cu ajutorul algoritmului de control optimizat prin metoda ”molie-flacăra” a convertorului Boost-KY

Santosh D. Gadekar[1], Murali M.[2]
[1]Cercetător științific, Facultatea de Inginerie Electrică, Universitatea Medi-Caps, Indore, MP, India.
[2]Profesor asociat, Departamentul de Inginerie Electrică la Universitatea Medi-Caps, Indore, MP, India
Rezumat. Automobile electrice au căpătat un rol important în viitorul sistem de transport din cauza disponibilității tot mai reduse şi a costurilor tot mai mari ale combustibililor fosili, precum și a preocupărilor tot mai mari legate de impactul încălzirii globale. Prin urmare, obiectivul principal al acestei cercetări este dezvoltarea unui sistem de încărcare a vehiculelor electrice eficient și durabil bazat pe energie fotovoltaică (PV), utilizând producția de energie fotovoltaică viabilă la nivel mondial. A fost introdus un convertor Boost-KY îmbunătățit pentru a contracara limitarea inerentă a tensiunii scăzute de ieșire a panoului fotovoltaic. Acest convertor atenuează în mod eficient undele de tensiune și de curent, asigurând astfel o sursă de alimentare stabilă pentru încărcarea vehiculelor electrice. În plus, a fost implementat controlerul MFO-PI (Moth Flame Optimized Proportional Integral) pentru a regla funcționarea convertorului, demonstrând o competență excepțională în atenuarea imprevizibilității ieșirii PV. Simularea MATLAB este realizată pentru a valida performanța sistemului propus. Cele mai notabile rezultate ale acestui studiu includ obținerea unei eficiențe maxime impresionante de 96.21% și o valoare remarcabil de scăzută a Distorsiunii armonice totale (THD) de 1.04%. Un sistem de încărcare a vehiculelor electrice bazat pe panouri fotovoltaice nu numai că reduce dependența de rezervele limitate de combustibili fosili, dar contribuie și la conservarea mediului, ceea ce este în conformitate cu eforturile globale de combatere a schimbărilor climatice. În plus, sistemul îndeplinește cerințele stricte ale standardului IEEE 519, făcându-l un catalizator pentru introducerea de soluții de energie curată în sistemul de transport al viitorului.
Cuvinte-cheie: sistem fotovoltaic, automobil electric, convertor Boost-KY îmbunătățit, controler PI optimizat cu algoritmul ”molie și flacăra”.

Оптимизация зарядки электромобилей с помощью оптимизированного с помощью метода "Мотылек-Пламя» ПИ-регулятора бустерного KY-преобразователя

Сантош Д. Гадекар[1], Мурали М.[2]
[1]Научный сотрудник, факультет электротехники, Университет Medi-Caps, Индор, штат Массачусетс, Индия
[2]Доцент кафедры электротехники университета Medi-Caps, Индор, штат Массачусетс, Индия

Аннотация. Электромобили играют важную роль в транспортной системе будущего в связи с уменьшением доступности и ростом стоимости ископаемого топлива, а также растущими опасениями по поводу последствий глобального потепления. Таким образом, основной целью данного исследования является разработка эффективной и устойчивой системы зарядки электромобилей на основе фотоэлектрических элементов, использующей глобальные возможности производства фотоэлектрической энергии. Для борьбы с ограничениями, связанными с низким выходным напряжением фотоэлектрических панелей, был разработан усовершенствованный преобразователь Boost-KY. Этот преобразователь эффективно снижает пульсации напряжения и тока, обеспечивая тем самым стабильное электропитание для зарядки электромобилей. Кроме того, для регулирования работы преобразователя был применен оптимизированный пропорционально-интегральный (MFO-PI) контроллер Moth Flame, демонстрирующий исключительную эффективность в снижении непредсказуемости выходного сигнала фотоэлектрических панелей. Для подтверждения эффективности предложенной системы было проведено моделирование в MATLAB. Наиболее примечательные результаты данного исследования включают достижение впечатляющего максимального КПД 96.21% и удивительно низкого значения суммарных гармонических искажений (THD) 1.04%. Система поддерживает постоянный уровень напряжения и тока как для фотоэлектрических панелей, так и для аккумулятора EV, обеспечивая надежное энергоснабжение. Значимость полученных результатов подчеркивается их потенциалом для решения важнейших задач в области устойчивого развития транспорта и интеграции возобновляемых источников энергии. Система зарядки электромобилей на основе фотоэлектрических панелей не только снижает зависимость от ограниченных запасов ископаемого топлива, но и способствует сохранению окружающей среды, что согласуется с глобальными усилиями по борьбе с изменением климата. Кроме того, система соответствует жестким требованиям стандарта IEEE 519, что делает ее катализатором внедрения экологически чистых энергетических решений в транспортную систему будущего.

Ключевые слова: фотоэлектрическая система, электромобиль, улучшенный Boost-KY-преобразователь, оптимизированный методом «мотылек - пламя» ПИ-регулятор.

1. INTRODUCTION

Consuming fossil fuels has drawbacks like limited supply sources and environmental concerns. Due to the depletion of fossil fuel supplies, renewable energy alternatives have emerged [1]. There are various ways to lessen pollution caused by the burning of fossil fuels in terms of environmental problems. For the transportation of people and commodities, the transportation industry requires a substantial amount of oil and gas resources, which produces CO_2 emissions and environmental damage [2]. As consequently, electric vehicles (EVs) have been proposed and are now being utilized to reduce fossil fuel usage and CO_2 emissions. The controller of an EV uses electricity from the renewable energy sources or utility grid to charge the battery [3].The PV panels have become increasingly considered to be superior energy source solutions to charge EVs when compared to other renewable resources. Solar power plants are currently utilized as primary source of energy to charge EV batteries because of a range of benefits which includes as lower maintenance and operation costs, a low carbon footprint output, and the ability to be energy independent. [4, 5]. Some of the recent innovations introduced in the field of PV based EV charging station with their features and constraints are listed in Table 1. Integrating PV panels in series or parallel is not a realistic way to increase voltage or current due to the significant space and cost requirements. As a result, a DC-DC converter with a larger gain voltage conversion ratio is necessary to create substantial voltage outputs [6]. Boost converters are frequently used in PV applications to convert DC to DC voltage, although step-up voltage ratio is the only other option [7]. Additionally, the discontinuous input and output that results in gain swings in Boost converters necessitates the use of extra switching machines. Several architectures have employed Buck-boost converters for the functioning of MPPT in an effort to offset these problems, however these converters suffer from higher switching stress [8]. Additionally, the discontinuous input current of buck-boost converters prevents them from executing optimum MPPT in the lack of substantial coupling capacitors. These converters also require big input capacitors. Single Ended Primary Inductance Converter (SEPIC) and Cuk converter can now overcome the shortcomings of buck-boost converters. [9, 10]. However, these types of converters are incapable of generating significant speed up/down voltage and are confined to a moderate power range. Huge input and output inductors are necessary for high-powered operation, and the converter is badly affected by grid variations. The above limitations are overcome by using Improved Boost-KY converter. The proposed converter is designed by the incorporation of Improved Boost [11] and KY converter [12] to provide a higher voltage conversion ratio, making it well-suited for boosting the low-voltage output of PV panels to levels required for efficient battery charging or grid connection. This converter lowers the harmonic content and improves system functionality even more by ensuring a stable power supply for EV charging.

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Table 1

Recent innovations in PV based EV charging station

Methods	**Remarks**	
Fuzzy Logic Control (FLC) [13]	Contributions	Renewable energy integration, efficient charging, decentralized energy management and adaptability.
	Constraints	The scalability of the system for larger charging stations or grid integration present challenges.
Mixed Integer Linear Programming (MILP) [14]	Contributions	Profit maximization, optimal battery sizing, efficient resource utilization and grid stability.
	Constraints	The limitations include dependence on accurate data, computational complexity, reliance on load forecasts and high upfront costs for optimal solutions.
Fuel Cell–Electrolyzer Unit [15]	Contributions	Sustainability, cost efficiency, energy independence and reduced grid dependency.
	Constraints	Challenges related to the initial cost, weather dependence, and complexity of integrating multiple energy sources
Intelligent Energy Management Scheme (IEMS) [16]	Contributions	Peak load reduction, efficient energy management, grid impact reduction and cost effectiveness.
	Constraints	Integration challenges and limited grid scenarios.
Charging/Discharging Scheduling Algorithm [17]	Contributions	Charging satisfaction, economical operation, energy efficient operation and grid-load balancing.
	Constraints	Lack of energy storage and environmental considerations.

It is considered necessary to implement a proper controller to optimize the dynamic characteristics of the converter to provide a stable and controlled output. Because of its simple and feasible design, the operation of converters in a solar system is often regulated by using a PI controller [18]. Nevertheless, even minor load variations degrade the effectiveness of the controller, and its variables are difficult to adjust in non-linear applications such as PV systems. The trial and error method is the most frequently utilized PI controller tuning method, and it is error prone, time consuming, and inaccurate. The disadvantages of traditional tuning techniques are being addressed as computer technology and optimization approaches advance. A genetic algorithm is utilized to modify PI controller's factors; however, the computation time is long due to slow convergence, and imprecise population coding reduces the performance of GA. For PI parameter tuning, particle swarm optimization technique is used [19, 20]. Although the PSO has the advantage of rapid convergence, its application is restricted by the difficult of being trapped in local optima. GWO has fewer parameters, simpler principles, and is easier to implement than conventional optimization approaches such as PSO and GA [21, 22]. GWO [23], on the other hand, low solution accuracy, has slow convergence speed and is prone to falling into local optima. Therefore, to solve these problems, Moth Flame optimization algorithm is presented here. MFO-PI controller simplifies the adjustment of its parameters, making it more suitable for non-linear systems [24]. It avoids the need for manual, time-consuming, and error-prone tuning methods like the trial and error approach. It offers rapid convergence and efficiently searches for optimal controller parameters, reducing the time required for tuning.

This work proposes the PV based EV charging system using Improved DC-DC converter with optimized PI controller. The solar panel DC voltage energizes battery for EV charging whereas an excess energy from PV system is enhanced through the use of Improved Boost-KY converter and further supplied to the grid. The efficient proposed converter regulation is obtained by using MF optimized PI controller. Moreover, the MF optimized PI controller offers quick transient response and enhanced convergence speed compared to conventional PI controller. The grid supplies energy to the battery for EV charging during shortage of power from the PV system. This proposed work distinguishes itself from existing ones by offering a comprehensive and innovative solution that combines advanced converter technology and a specialized control strategy. While traditional converters struggle with fluctuations in PV panel output, this innovative converter ensures reliability in energy transfer for EV charging. The implementation of the MFO-PI controller is specifically designed to handle the unpredictability in PV output. Its exceptional proficiency in regulating the converter operation ensures that the system can adapt to varying conditions, maintaining stable power levels even when faced with fluctuations.

2. PROPOSED SYSTEM DESCRIPTION

The demand for EVs is growing by the day, and one of the most significant problems is a shortage of facilities for charging. Countries are striving for quick expansion of renewable energy to be used as a charging station source in order to lessen their carbon footprint. For the advantage of the system as a whole, this research designs an optimised PI controller combined with solar PV in an EV charging station. The schematic depiction of an organized efficient optimized control for a PV powered EV charging station is shown in Fig. 1.

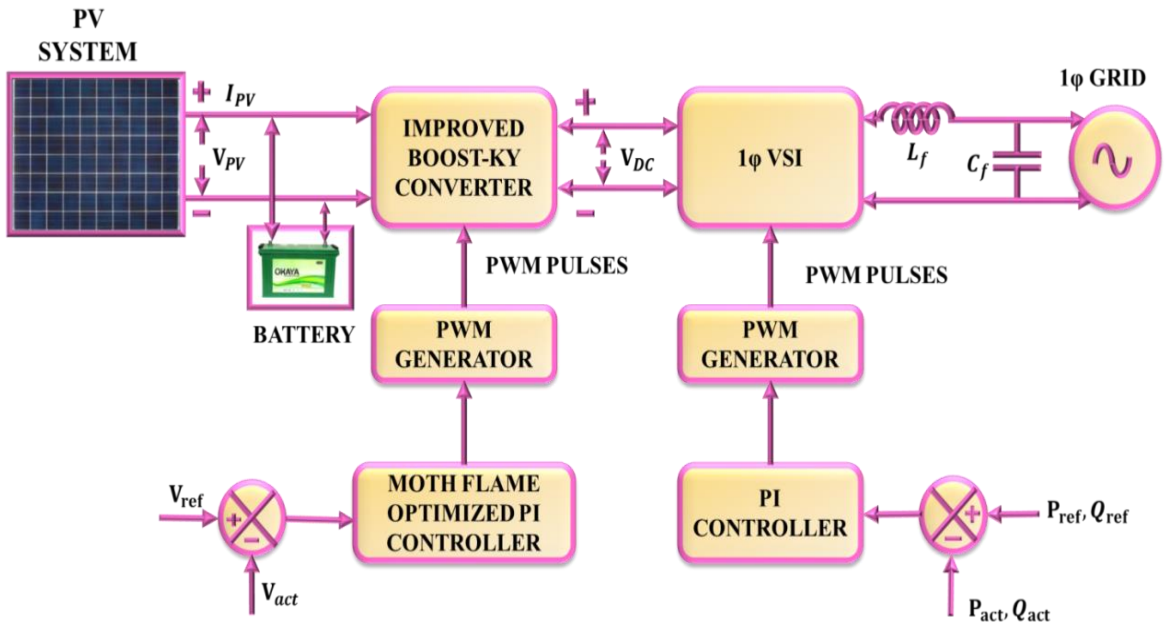


Fig. 1. PV powered EV charging station, using MF optimized PI controller.

In most cases, the electricity generated by a PV system is utilized to charge battery of an electric vehicle. To increase the excess PV voltage, an Improved Boost-KY converter is used in the proposed work. The proposed converter achieves high voltage gain, improves efficiency, and lowers costs. Nevertheless, voltage preservation is required to ensure efficient power production with minimal loss; therefore, the MF optimized PI controller is established. By adjusting the PI controller's parameters, the MFO helps to improve the system's efficiency and stability. The generated DC link supply is passed to single phase VSI for active AC conversion, together with a PI controller for voltage stabilisation. The LC filter connected to the system reduces harmonics and improves grid supply. The proposed converter achieves maximum efficiency with enhanced THD value. At times of power deficiency from PV system, the grid energizes the battery.

A. PV System Modelling

Photovoltaic cells are one of the fundamental elements of solar power plants that transform solar power into electrical energy. Fig. 2 depicts the corresponding circuitry of a PV cell and its components.

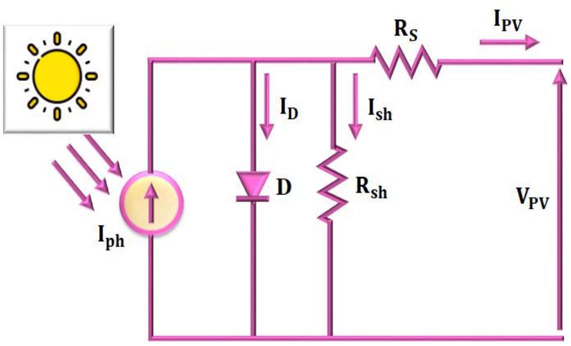


Fig. 2. Equivalent circuit of PV cell

Equations (1, 2, 3, 4, 5 and 6) can express mathematical formulas that describe the PV module in single diode model, which consists of series-connected PV cells.

$$I = I_{ph} - I_d - I_{sh} \quad , \tag{1}$$

$$I = I_{ph} - I_o\left(exp\left(\frac{V+R_sI}{aN_sV_t}\right)-1\right)-\frac{V+R_sI}{R_{sh}} \quad , \tag{2}$$

$$V_t = \frac{KT_c}{q} \, , \tag{3}$$

$$I_{ph} = \frac{G}{G_n}\left(I_{sc_n} + K_T\left(T_C + T_{cn}\right)\right) \quad , \tag{4}$$

$$I_o = I_{o_n}\left(\frac{T_c}{T_{C_n}}\right)^3 exp\left(\frac{qE_g}{ak}\left(\frac{1}{T_{c_n}}-\frac{1}{T_c}\right)\right) \, , \tag{5}$$

$$I_{0_n} = \frac{I_{sc_n}}{exp\left(\frac{V_{oc_n}}{aN_sV_{tn}}\right)} \tag{6}$$

Where I_{ph} -photo generated current; I_{sh} - current parallel resistance; I_o - diode saturation current; I_d -diode current; V -terminal's voltage, a -ideality factor; N_s - number of series cells; R_s - series resistance; V_t thermal voltage; K K - Boltzmann constant ; R_{sh} -Shunt resistance; T_C - PV cell's temperature in Kelvin; q - electron charge; G - solar irradiance; I_{sc_n} - short circuit current under standard test conditions (STC); K_T - temperature coefficient of I_{sc_n} ; V_{oc_n} - voltage of open circuit ; E_g -band gap energy. Due to the inconsistency of solar energy, the voltage provided by PV is generally insufficient for grid operation. As a result, converter deployment is essential and the proposed research produced a unique converter for voltage boosting, which is detailed below.

B. Improved Boost-KY Converter Modelling

Fig. 3 depicts an improved Boost-KY converter proposed in this paper to increase the excess PV voltage.

Fluctuations in voltage and current passing through converter components are demonstrated in various operation modes.

The converter in use is in continuous conduction mode (CCM). The filtering elements utilised by the Improved Boost and KY converters included inductor L_2 and capacitor C_o.

These converters share a common load. In Fig. 3 (a) & (b), the operating modes of the converter are indicated.

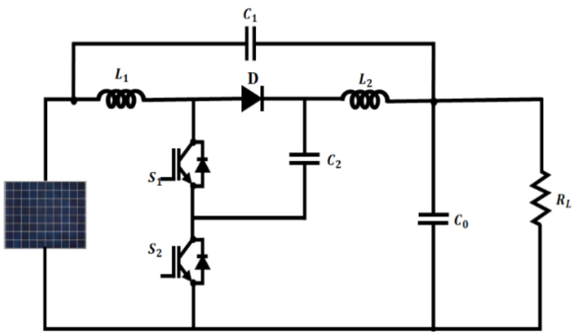


Fig. 3. Proposed Improved Boost-KY converter

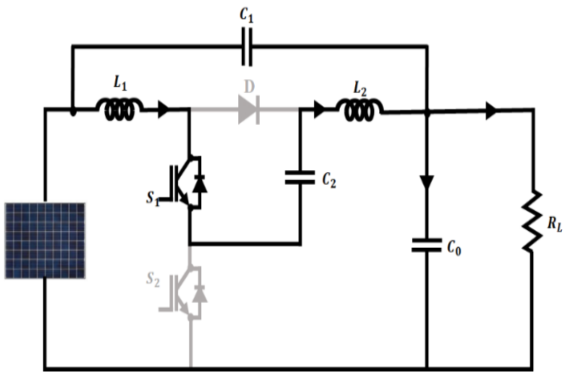


Fig. 3(a). Stage 1.

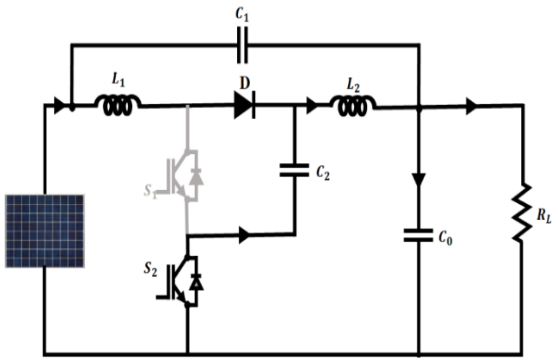


Fig. 3(b). Stage 2.

Stage 1

Operation at Stage 1: During this state, the switch S_1 is ON, the switch S_2 is OFF, and diode D is reverse biased due to the voltage between the inductor L_2.

The capacitor C_1 releases its stored power and charges the inductor L_2, whereas the capacitor C_2 releases its saved charges to the load and the output capacitor C_o. Furthermore, Table 2 shows the charging conditions of the converter's various components.

Table 2
Improved Boost KY Converter switching state

Switch S_1, S_2	Diodes D	Inductors L_1	Inductors L_2	Capacitors C_1	Capacitors C_2	Capacitors C_o
0,1	1	↑	↑	↓	↓	↑
1,0	0	↓	↓	↑	↑	↓

↓ *–discharging*, ↑ *–charging*

Operation at Stage 2: During this mode 2, the switch S_1 is OFF, switch S_2 is ON, and diode D is forward biased and conducting. In contrast to mode 1, the inductors L_1 and L_2 are discharging while the capacitors C_1 and C_2 are charging.

Considering the subsequent path: $V_{PV}, L_1, C_1, L_2, C_2$ and C_o with the assistance of KVL.

$$V_{PV} + V_{L_1} + V_{C_1} + V_{L_2} + V_{C_2} + V_{C_o} = 0 \quad (7)$$

The voltage over the capacitor C_1 is specified as follows:

$$V_{C_1} = V_{PV} \quad (8)$$

Assuming the switch S_1 has been turned ON at interval DT in stage 1, the voltage across inductor L_1 is expected to be,

$$V_{L_1} = V_{PV} \quad (9)$$

Examine the outermost route in mode 2 and use KVL,

$$-V_{PV} + V_{L_1} + V_{C_1} + V_o = 0 \quad (10)$$

On considering $V_{PV} = V_{C_1}$,

$$-V_{PV} + V_{L_1} + V_{PV} + V_o = 0 \quad (11)$$

$$V_{L_1} = -V_o \quad (12)$$

When there is a periodic operation, average voltage across the inductor is zero.

$$(V_{L_1,sw\,on})(DT) + (V_{L_1,sw\,off})(1-D)T = 0 \quad (13)$$

$$V_{PV}(DT) - V_o(1-D)T = 0 \quad (14)$$

Where switch's duty ratio is represented by D. The V_o is written as,

$$V_o = V_{PV}\left(\frac{D}{1-D}\right) \quad (15)$$

The duty cycle is specified as,

$$D = \frac{V_o}{V_o + V_{PV}} \quad (16)$$

Thus, the proposed Improved Boost-KY converter is able to employ in a variety of applications. Whenever the converter has no losses, the energy received by the load is equal to the converter input power,

$$P_{PV} = P_o \quad (17)$$

Input current has a value equal to I_{L_1}

$$P_{PV} = V_{PV} I_{PV} = V_{PV} I_{L_1} \quad (18)$$

The predicted output power P_o is,

$$P_o = V_o I_o \quad (19)$$

$$V_{PV} I_{L_1} = V_o I_o \quad (20)$$

The average inductor current is calculated to be,

$$I_{L_1} = I_{PV} = \frac{V_o I_o}{V_{PV}} = \frac{V_o^2}{V_{PV} R_0} \quad (21)$$

When S_1 is turned off, the modification in i_{L_1} is displayed as,

$$\Delta i_{L_1} = \frac{V_{PV} DT}{L_1} = \frac{V_s D}{L_1 f} \quad (22)$$

The ripple voltage at the output is expressed as,

$$\Delta V_o = \Delta V_{C_O} = \frac{V_o D}{R_O C_O f} \quad (23)$$

C. Moth Flame Optimized PI Controller Modelling

A PI controller is a form of closed loop controller that is widely utilized in a wide range of applications. A PI controller requires to preserve the desire voltage by varying duty factor of the Improved Boost-KY converter's output based on the difference among organised and real output voltages. It results in higher peak variations and a slower response time, As a result, optimum tuning is critical, which MFO [25] achieves in this research. To improve performance of the proposed converter, and parameters of a PI controller are modified using MFO.

MFO Algorithm

One of the population-specific techniques influenced by moth flying and navigation behaviours is MFO. Throughout the night time, the moths fly at a position that is set to the moon. As a result, it is capable of flying in a direct path for a considerable distance. In the occurrence of a small distance artificial illumination, nevertheless, moth is going to fly in a spiral pattern as it attempts to keep a fixed position towards the light source. Because of the presence of the solution sets during the process of optimisation, this method has a strong potential to avoid local optimum. The MFO's most recent and most effective approach serves as a guide for moths. Because of this circumstance, the moths are unable to be contained in lack of progress, and so convergence is confirmed.

The calculated representation of the MFO technique, that involves a fixed of rules, is depicted in the matrix as given as:

$$M = \begin{bmatrix} m_{1,1} & \cdots & m_{1,d} \\ \vdots & \ddots & \vdots \\ m_{n,1} & \cdots & m_{n,d} \end{bmatrix} \quad (24)$$

Where m the overall moths and number of dimensions is indicated by n. For every month, the statement is put forward that an array occurs for recording related fitness values as given as:

$$OM = \begin{bmatrix} OM_1 \\ OM_2 \\ \vdots \\ OM_n \end{bmatrix} \quad (25)$$

Where n is the number of moths. The fitness value for each moth is the final output of the fitness function. Since matrix M is a constant encoding, it must be decrypted into a transformation integer in order to express a possible meeting process utilising the topology sort process. Each moth's location vector is then passed to the fitness function. The result of this function is assigned to relevant moth as OM_1. Flames constitute another crucial feature via the MFO algorithm, that is represented in the matrix, that's similar to the moth's matrix seen following to enhance the possibilities.

$$F = \begin{bmatrix} F_{1,1} & \cdots & F_{1,d} \\ \vdots & \ddots & \vdots \\ F_{n,1} & \cdots & F_{n,d} \end{bmatrix} \quad (26)$$

Here the d is the dimension parameter and denotes no.of flames. The function is related with the construction of initial solutions and the computation of objective values, for which several randomized distributions are has been used. It needed to be emphasised that both solutions used moths and flames. The variations between them were caused by the treatment approach and the updating of both solutions in each cycle. Moths are regarded to as original search agents since they roam about search space. Flames, on the other hand, are recognised as the finest position of moths that gains so far. As a result, if a better option is found, each moth searches for a flame and jumps into it. A moth's optimal approach is never lost due to this technique. The MFO method is made up of three tuple approximating global optimal functions that are as given as:

$$MFO = (I, P, T) \quad (27)$$

If I is the randomised moth's population activation function, and appropriate value of fitness is summarised as given as:

$$M_{(i,j)} = (ub(i) - lb(i) rand() + lb(i)) \quad (28)$$

Where ub and lb are variables lower and upper limits, respectively. Following function systematic model is:

$$I : \varnothing \rightarrow \{M, OM\} \quad (29)$$

The e P function, changes the moths throughout the search space. This function obtains the M matrix and eventually yields its modified version.

$$P : M \rightarrow M \quad (30)$$

T function returns true if the termination requirement is fulfilled. At that point, if termination requirement is dissatisfied, the T function returns false:

$$T : M \rightarrow \{true, false\} \quad (31)$$

A logarithmic spiral is defined as follows for the MFO algorithm:

$$S(M_i, F_j) = D_i.e^{bt}.cos(2\pi t) + F_j \quad (32)$$

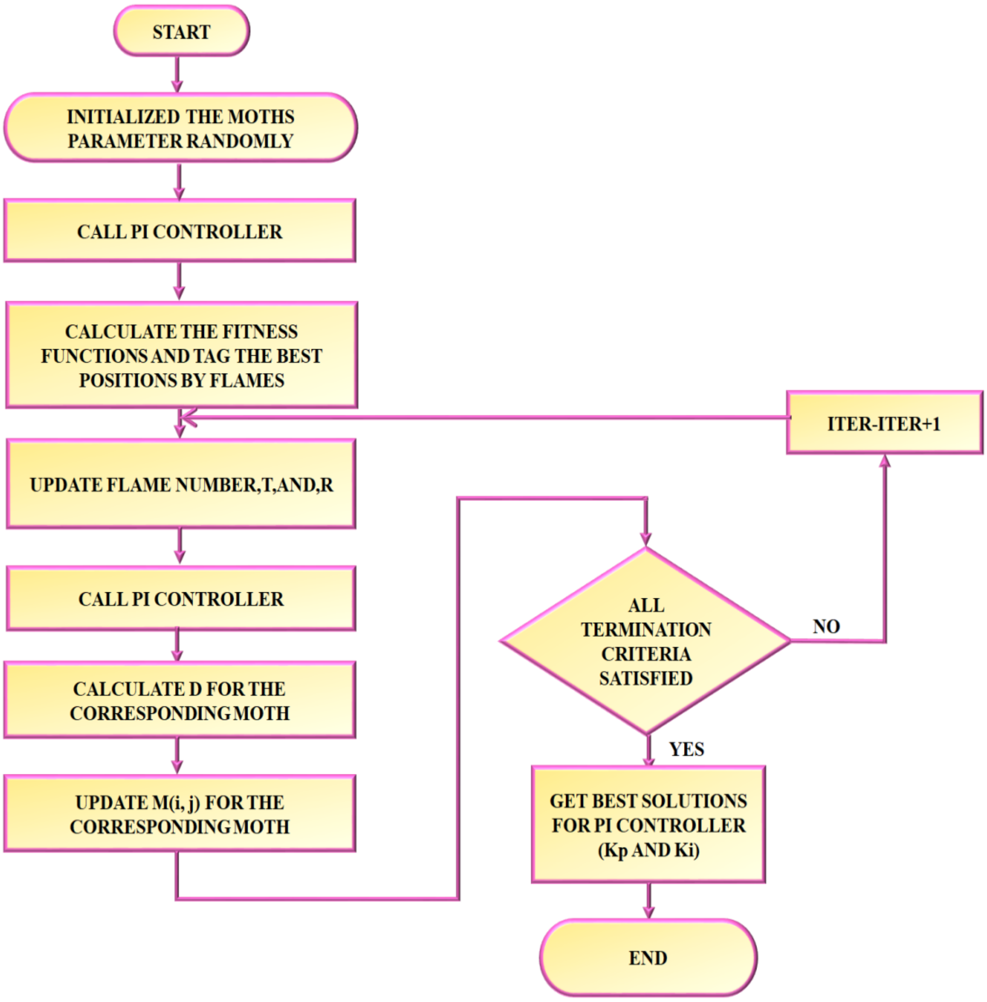


Fig. 4.Flowchart of MF optimized PI controller.

Fig. 4 illustrates the flowchart diagram for MF optimized PI controller.

In this equation, D_i denotes distance of the $i-th$ moth for $j-th$ flame, b is logarithmic spiral, and t is random number. D is estimated as given as:

$$D_i = |F_j - M_i| \quad (33)$$

Where M_i represents the $i-th$ moth, F_j represents the $j-th$ flame. A moth can navigate around a flame using the spiral equation, but it is not fundamentally in space between them. Adaptive convergence over the course of iterations, constant r decreases from -1 to -2 to increase convergence around the flames. The amount of flames is flexibly reduced by increasing the no. of iterations. In this scenario, the subsequent formula is used subject to the specified condition:

$$flame\,no = round\left(N - l\right) \times \frac{N-1}{T} \tag{34}$$

Where, l denotes current number of iterations, N denotes the maximum amount of flames, and T denotes total number of iterations. The moths successfully adjust their positions in relation to the most optimal flame in the last steps of iterations.

D. Implementing the MFO based PI controller in the MATLAB environment

Define the objective function: Define an objective function that quantifies the performance of the control system. This function typically evaluates how well the PI controller performs based on certain criteria like overshoot, settling time or error. The objective function should take the PI controller parameters as input and return a fitness value to be minimized or maximized by the MFO.

Initialize the Moth-Flame Algorithm parameters: Set an algorithm parameters such as the population size, the maximum number of iterations, the range of controller parameter values and other control parameters like the flame intensity factor, and other parameters specific to the MFO algorithm.

Generate an initial population: Create an initial population of potential PI controller parameter sets. These could be developed at random or based on some prior knowledge.

Perform the MFO optimization: Inside a loop, execute the MFO algorithm to optimize the PI controller parameters. The algorithm involves the following steps:

a. Evaluate the fitness of each potential solution using the objective function.

b. Update the position of moths in the population based on their fitness and the movement equations of the MFO.

c. Apply the MFO specific operations like selecting a leader moth, calculating the flame intensity, and updating positions accordingly.

Termination condition: Decide on a termination condition, such as a maximum number of iterations or reaching a specific fitness threshold.

Extract the optimized PI controller parameters: After the MFO optimization is complete, extract the optimized PI controller parameters from the best solution found.

Implement the PI controller: Use the optimized PI controller parameters to implement the controller.

E. Single Phase VSI Modelling

Fig. 5 depicts a single phase voltage source inverter system for converting a constant DC link voltage to an alternating current. VSI is indeed the power part of a converter system. It is a type of inverter used to convert a single-phase DC voltage into a single-phase AC voltage with controllable amplitude and frequency.

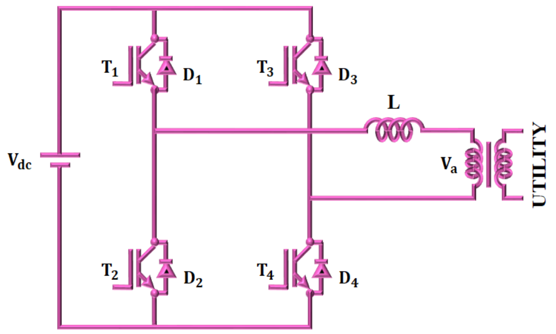


Fig. 5. Single phase VSI

It consists of a direct current voltage source, four switches T_1, T_2, T_3, T_4 and four diodes D_1, D_2, D_3, and D_4. The inverter output is transmitted to grid via an LC filter, which reduces harmonics while maintaining a sinusoidal waveform.

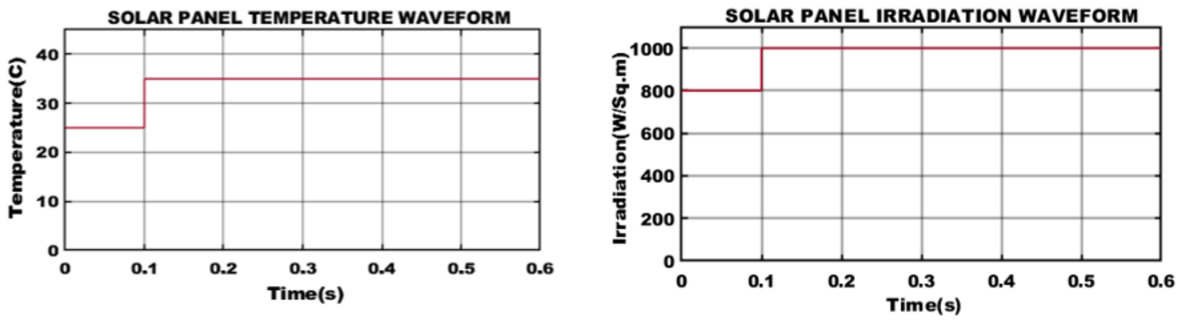
3. RESULTS AND DISCUSSION

This paper proposes an efficient PV-based EV charging system that employs an improved DC-DC converter with an optimised PI controller. The weak solar panel dc voltage has been enhanced by using an Improved Boost-KY converter that has reduced voltage and current ripple factors. Using an MF optimised PI controller, the suggested converter regulation is effective. Furthermore, as contrasted with conventional PI controllers, the MF optimised PI controller provides faster transient response and faster convergence speed. The proposed system's parameter specifications are presented in Table 3.

Table 3
Design of Parameter

Parameter	Specification
Solar PV System	
Series connected solar PV cells	36
Open Circuit Voltage	12V
Short Circuit Current	8.33A
Peak Power	10KW, 10 Panels
Improved Boost-KY converter	
L_1, L_2	1.2mH
C_1, C_2	4.7 μF
C_0	2200 μF
Switching Frequency F_s	10KHZ

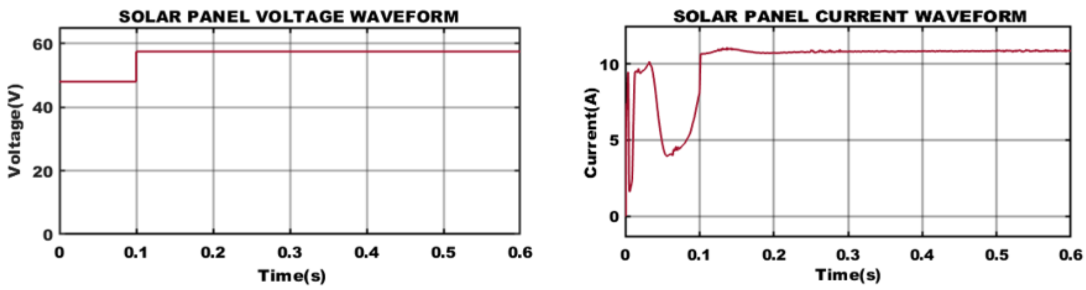
The waveforms for PV panel temperature and irradiance are shown in Fig. 6. The constant temperature and irradiation 35℃ &1000 (W/Sq.m) attained, which is represented in Fig. 6(a) & (b) respectively.



(a) (b)

Fig. 6. Waveforms indication of Solar panel (a) Temperature (b) Irradiation.

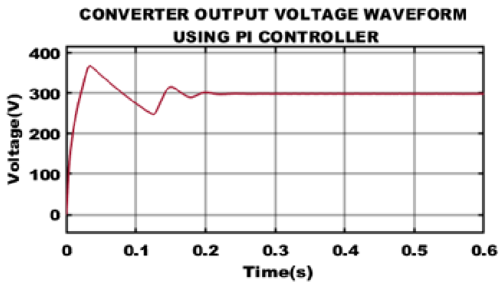
PV panels are affected by nonlinear variables like as temperature and irradiation. As a result, the power produced by of the PV panel fluctuates often and generates only a small amount of dc voltage. Because this voltage variation has a significant impact on the devices utilised and the overall system efficiency, a steady voltage of 58V DC is obtained, as presented in Fig. 7 (a). The solar panel's current waveform is shown in Fig. 7(b), that obviously indicates that the current is initially zero and increases gradually to a steady level of 11 A after some time.



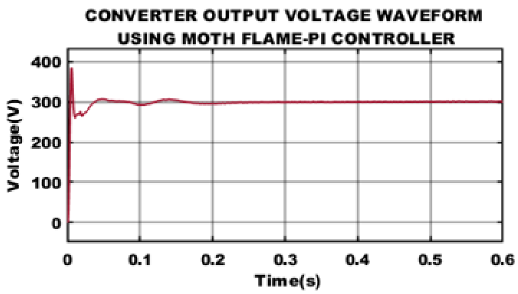
(a) (b)

Fig. 7. Waveforms indication of Solar panel (a) Voltage (b) Current.

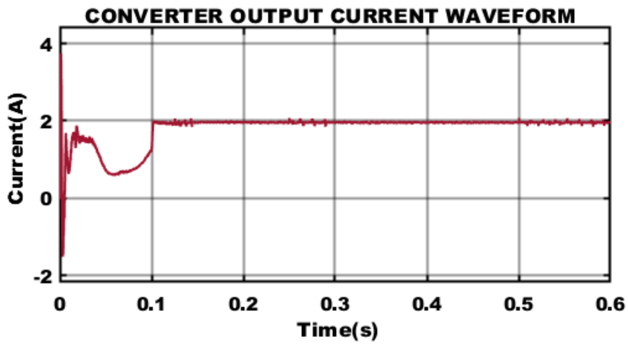
Fig. 8 depicts the voltage that is produced of the Improved Boost-KY converter with PI and MFO controlled PI controller. As a result, the Fig. 8 (a) & (b) clearly shows that the estimated settling time of the converter with MFO tuned PI is less than that of the converter with PI controller. The current become stable after 0.3 seconds with small amount of distortions, which is represented in Fig. 8(c).



(a)



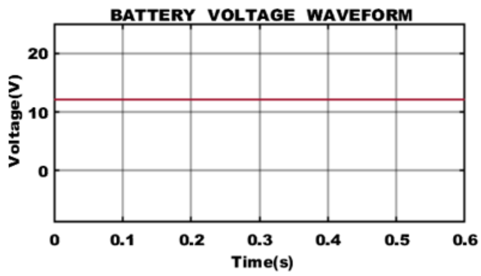
(b)



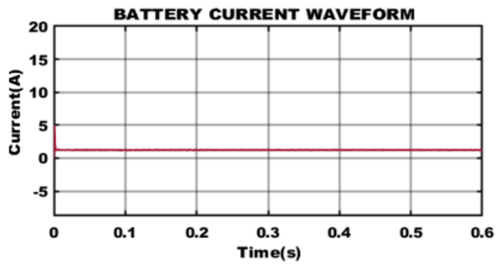
(c)

Fig. 8. Waveforms indication of proposed converter voltage (a) Using PI controller (b) Using MF optimized PI controller (c) Current output waveform.

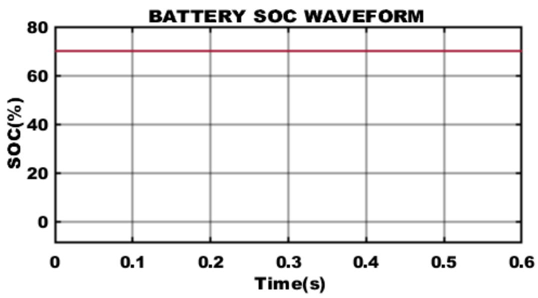
Fig. 9 (a) and (b) illustrate a waveform reflecting the voltage and current of a charge storage battery. It preserves the extra energy generated by the PV panel, depending on its capacity. From the observation, the stable voltage and current value of 12V and 1A is maintained correspondingly. The battery SOC needs to be maintained within a specific range, which in this case is 70%, as displayed in Fig. 9 (c).



(a)



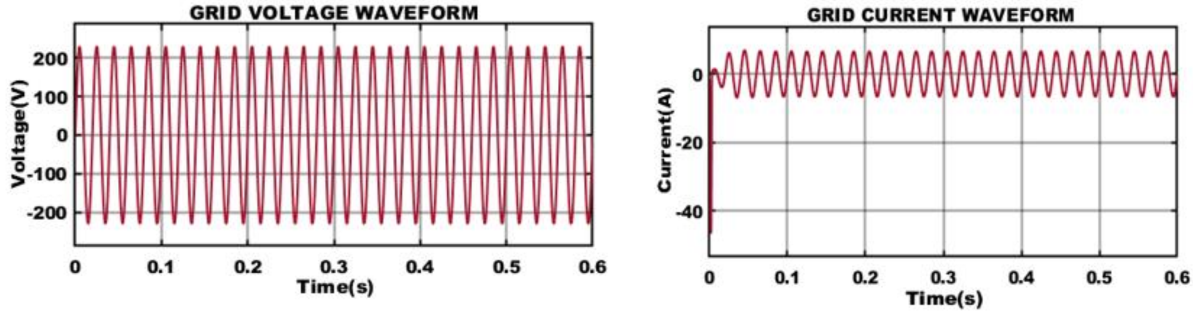
(b)



(c)

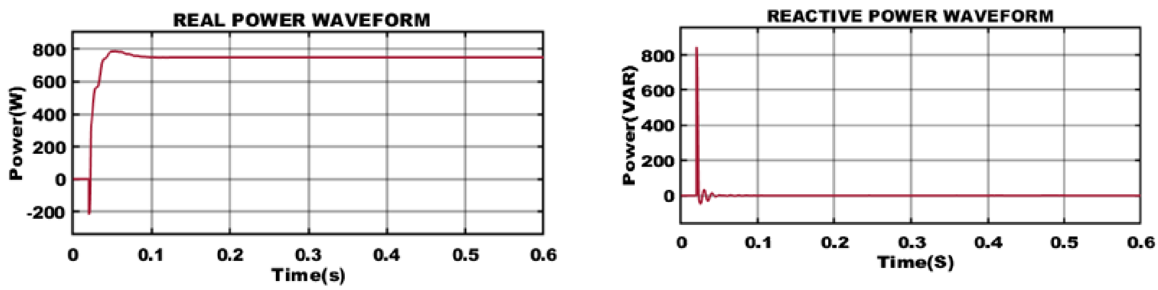
Fig. 9. Waveforms indication of EV battery output (a) Voltage (b) Current (c) SOC.

Figures 10 (a) & (b) depicts waveforms for grid voltage and current. A steady grid voltage of 230V is preserved without distortion in the intended three grid system. In a similar way a steady grid current of 8A remains consistent, which improves grid performance. The proposed system attains the stable real and reactive power for single phase grid is indicated in Fig. 11.



(a) (b)

Fig. 10.Waveforms indication of grid output (a) Voltage (b) Current.



(a) (b)

Fig. 11. Waveforms indication of (a) Real power (b) Reactive power.

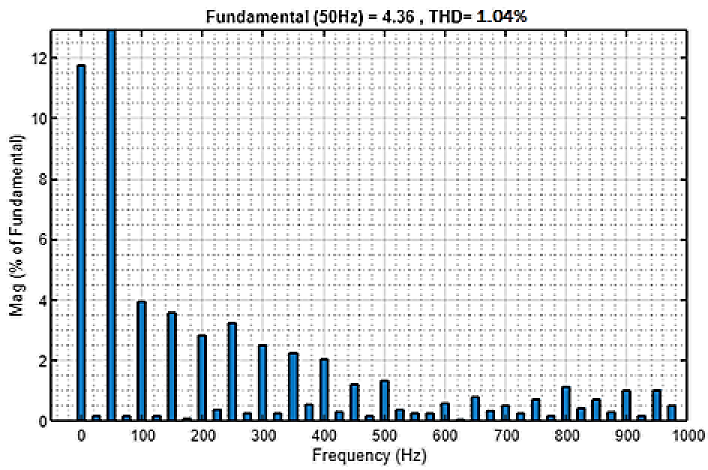


Fig. 12. THD waveform

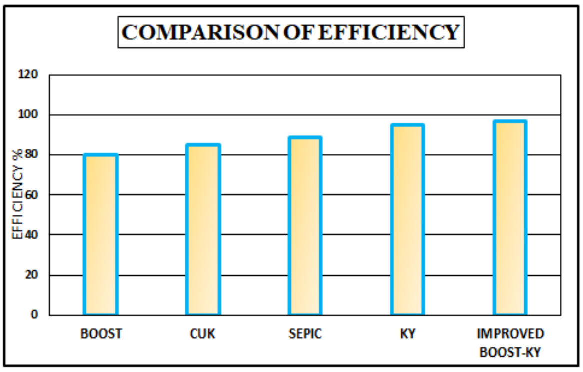
The proposed system achieves minimal THD value of 1.04%, which is satisfies the requirement of IEEE 519 standard. Table 4 & 5 presents a comparison of efficiency & THD with various converters to the proposed Improved Boost-KY. The proposed converter achieves an enhanced efficiency of 96.21% with a minimized THD value of 1.04%. The corresponding plots are represented in Fig. 13.

Table 4
Comparison Analysis of Efficiency

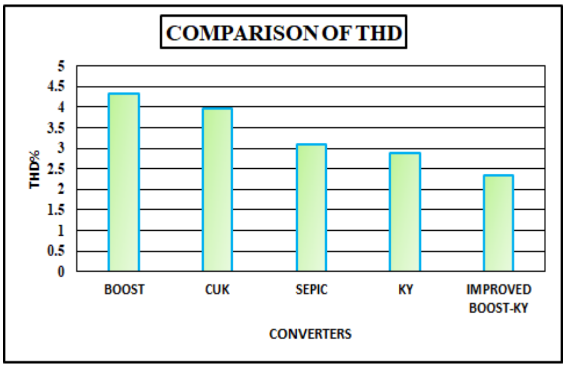
Converter	Components				Efficiency
	C	L	D	S	
Boost [26]	1	1	1	1	80%
Cuk [27]	3	2	2	1	85%
SEPIC [28]	3	2	1	1	88.82%
KY [29]	2	1	1	2	95%
Proposed Improved Boost-KY	3	2	1	2	96.21%

Table 5
THD values

Converter	THD%
Boost[26]	4.32%
Cuk[27]	3.98%
SEPIC[28]	3.08%
KY[29]	2.89%
Proposed converter	2.35%



(a)



(b)

Fig. 13.Comparison analysis of (a) Efficiency (b) THD.

Table 6
Controller transient response comparison

CONTROLLER	Rise Time t_r	Peak Time t_p	Settling Time t_s
PI CONTROLLER [18]	0.06	0.03	0.35
MFO-PI CONTROLLER	0.03	0.02	0.26

Based on the findings in Table 6, In regard to rise time t_r, peak time t_p and settling time t_s, the proposed MF optimised PI controller is superior to the traditional PI controller. The proposed MF optimised PI controller has a fast settling time of 0.26 seconds. Table 7 provides an effectiveness analysis of various optimization algorithms. The MFO algorithm stands out as the most effective among the algorithms considered in this analysis, delivering a superior solution with a faster convergence speed and minimal computational time. This comparison highlights the MFO algorithm's suitability for the optimization task at hand, where both optimization quality and computational efficiency are essential factors to consider.

Table 7

Effectiveness Analysis of Optimization Algorithms

Algorithms	Objective Function Value	Convergence Speed	Computational Time
MFO	100	50 iterations	0.5s
Genetic Algorithm [19]	120	75 iterations	2.2s
Particle Swarm Algorithm [21]	110	60 iterations	1.8s
Simulated Annealing [30]	115	80 iterations	3.1s
Grey Wolf Optimizer [23]	105	55 iterations	1.5s

Thus the proposed work's exceptional proficiency in regulating the converter operation ensures that the system can adapt to varying conditions, maintaining stable power levels even when faced with fluctuations.

4. CONCLUSION

The primary goal of this study is to enhance the performance of a Boost-KY converter for efficiently converting minimal PV voltage output to higher, more stable voltage levels. To achieve this objective, the following tasks were addressed: An enhanced Boost-KY converter is employed to effectively manage the fluctuations in PV output voltage resulting from the dynamic interplay of irradiance and unpredictable weather conditions. Furthermore, an MFO-PI controller is used to oversee the enhanced Boost-KY converter, significantly mitigating the inherent unpredictability of PV output. As a result of these efforts, the study found that the MFO-PI controller, is highly effective in managing a wide range of peak levels in PV systems operating under various conditions. Additionally, it is observed that MF optimized PI controller achieved a quicker settling time of 0.26 seconds compared to a conventional PI controller. The proposed system's performance was rigorously evaluated using MATLAB simulations. The results demonstrated that the system achieved a maximum efficiency of 96.21% and exhibited low THD.Incorporating energy storage systems, such as batteries or supercapacitor, into the PV-based EV charging system can provide uninterrupted power supply and grid services. Future studies could focus on the optimal integration, control and sizing of energy storage components to maximize system resilience and reliability.

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Information about authors.

Santosh Dinkar Gadekar, research scholar in the Department of Electrical Engineering at Medi-Caps University, Indore, MP, India. . His current research areas of interest are Electrical Machines, Operation and control of Power Systems, E-mail: santoshgadekar.919@gmail.com

M. Murali Professor in the Department of Electrical Engineering at Medi-Caps University, Indore, MP, India. His current research areas of interest are Transmission Pricing, Artificial Intelligence & E-mail: murali233.nitrv@gmail.com