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Hybrid Optimization Based Fuzzy Logic Controller for Standalone PV Battery System with Two-Stage Converter

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Abstract:

Standalone solar PV systems are being considered potential solutions to electrical problems in areas without a grid. It can be difficult to maximize the performance of the photoelectric system, DC-DC inverter, DCAC converter, and control systempotential while making these devices. In this study, a freestanding two-stage technique using a bidirectional converter is introduced together with a boost converter, an inverter, and batteries. Fuzzy logic controller for a Standalone PV battery and a two-stage converter system using a hybrid optimisation algorithm (Chaotic Hybrid Butterfly Optimisation Algorithm with Particle Swarm Optimisation) is presented in this study. In numerical optimisation problems with a high dimension, the hybrid HPSOBOA converges fast and maintains stability better than the PSO, BOA, and other categories of well-known swarm optimisation methods. Simulink is used to design and a PV module, a DC-DC converter, and a fuzzy logic controller are used to simulate an MPPT systemin order to be successful. Normal solar PV modules have very low operating efficiencies; maximum power point trackers (MPPT) are paired with the system to increase operational efficiencies and save installation costs. In order to test and assess the newly designed control strategy under various conditions, such as load changes,extensive MATLAB simulations were performed. The output of the system was evaluated with the aid of several MATLAB simulations.

Keywords **—Standalone PV Battery system, Fuzzy Logic Control (FLC), Boost Converter, butterfly optimization algorithm (BOA); particle swarm optimization (PSO), Two-Stage converter**

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I. INTRODUCTION

Renewable energy sources have emerged as the most efficient source of energy as a result of increasing pollution levels and the quick depletion of fossil fuels. The expense and intermittent nature of these renewable sources, however, present the biggest integration difficulty. One of the most effective renewable energy sources is photovoltaic (PV) energy. However, it is not accessible at night. [1] Because they are clean and environmentally sustainable, PV systems are being employed more and more as distributed generators all over the world. PV panels are now far more inexpensive, however they mostly run on unsteady DC power. Therefore, DC-DC or DC-AC conversions are needed before the PV signals may be sent to the output load or connected to the grid power. A battery bank often serves as the component for energy storage in standalone PV units because PV electricity is unstable. A standalone PV system is made up of a PV module, a DCDC converter, a battery, an inverter, and any required AC or DC loads. A storage system is required to meet the demand loads throughout the day because a standalone PV system is not connected to the utility grid [4].

When the electricity produced by the PV is greater than the necessary load requirement, the battery stores the extra energy. A freestanding PV system may have DC or AC loads of many types [5]. The effectiveness of a standalone photovoltaic system with battery storage. Depending on the varying weather conditions, the boost converter's output in current and voltage changes. The PV system's ability to deliver power is based on the sun's illumination, which changes over time. [6] As a result, the system's output of power, measured in terms of voltage and current, is changeable. An MPPT algorithm is used to track the maximum power point in order to work as efficiently as possible. The converter is employed to generate a constant output of DC voltage, which can then be supplied into an inverter to generate alternating voltage, which can subsequently be fed into a grid to satisfy societal energy needs. [7]

There is a point in the I-V and P-V curves where the system's instantaneous I and V can provide the most power, it is noted. The duty cycle of the DC-DC converter is altered to produce the highest power. [8] The Maximum Power Point Tracking (MPPT) is used to accomplish this is necessary to get the most out of PV systems. PV systems behave differently in various weather scenarios. Multiple Local Maximums (LM) and a Global Maximum (GM) can be seen on the I-V and P-V curves when partial shading (PS) is present. Usually, partial shading is caused by clouds, shadows, or uneven illumination. [9]

By adjusting the amount produced from each energy source in accordance with the load demand, integration of two or more energy sources may give the greatest strategy to increase power generation. Developing and optimising the highest power point tracking and control of a multi-source alternative power generating system made up of photovoltaic (PV) modules, wind turbines, and other sources is the major goal of this project. [10]

The hybrid meta-heuristic algorithm approach, which integrates the fundamental PSO and BOA with the chaotic theory, is also applied in the enhanced method to increase the efficacy of the algorithm for high-dimensional optimisation issues that we presented. A unidirectional control technique is suggested for modifying the capacity for enhanced algorithm's both local and international search capabilities after a detailed analysis of the power exponent's control parameter in BOA. [11]

The regulation of the DC bus voltage and the two-stage converter using FLC in various weather scenarios are the main topics of this thesis. The effectiveness of the FLC approach is thoroughly addressed. Then, one of the main contributions of this work relative to that is explored in detail with regard to the tuning of the suggested Two-Stage battery charger based on PSO optimisation technique. [12] This suggests an HPSOBAO based on FLC. This can help with issues with inverter output harmonics, system implementation, losses, switching strategies, and power factor that are related to minimising PV output oscillations. The optimal design required to develop the proposed solution is produced through the simulation of a composite PV module and selected buck-boost converter.

II PROPOSED SYSTEM

A typical PV generation system has a two-stage structure, with the first stage typically consisting of a DC/DC converter that extracts electricity from PV arrays. A DC/AC converter serves as the second stage, guaranteeing a steady DC-link voltage and preserving power distribution between the AC and DC sides.The DC-link voltage, also referred to as the DC-link voltage, is necessary to keep both stages operating steadily. In the DC link between the two stages, it is applied across the capacitor.

A. Main Circuit

The schematic of a two-stage converter is shown in Figure 1. It can be seen that a storage device, DC-DC and DC-AC converters, as well as a PV power supply via a bidirectional converter, all provide the load. The control systems for the two stages are also part of the system.

a. The PV Array

Solar PV modules are connected in parallel and series to create solar PV arrays, which can produce more power. A total input capacity of six parallel and four series panels of 5 kW are used to make up the PV array for this article. A PV panel can be connected either directly or over a DC/DC converter to the inverter because it generates DC power out in the country. Fortunately, this will bring down the overall cost. A PV cell essentially consists of a semiconductor diode with a P-N junction that converts light directly into electricity.

b. Power converters DC/DC

In PV systems, Converters for DC/DC power are used the output voltage to be altered. To track the power that is available from the PV panel, a DC/DC converter is often installed between the panel and the load. It is helpful for a PV system whose output is unreliable and erratic. The DC output voltage stability can be improved with a DC-link capacitor, as a result, lessen the impact of variation Using both AC and DC converters, the PV system on the AC output.

c. DC/AC inverter

Known sinusoidal AC output from a power electronic converter with adjustable frequency and magnitude is produced when DC electricity is converted into AC power by an inverter. Unlike a voltage source inverter (VSI), a current source inverter (CSI) gets a steady current supply which receives a constant voltage supply. Applications that require very high-Power AC motor drives commonly use CSI.

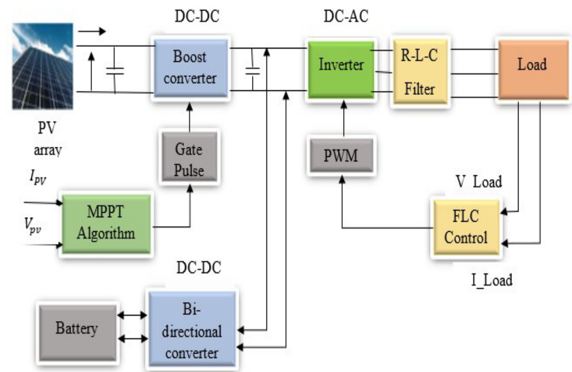


Fig.1 Proposed Block diagram

d. Maximum Power Point Tracking

The conversion of solar energy into usable electrical energy by the PV system has a subpar overall efficiency. The system's efficiency is raised via the MPPT, or maximum power point tracking strategy, which makes use of one or more solar modules to maximise power. A non-linear output results from the interaction of temperature, resistance, and sun irradiation.

B. Working Principle of PV Array

A PV cell operates under the theory of the photoelectric effect, which is the phenomenon in which a substance absorbs light of a specific wavelength, causing an electron to be ejected from its conduction band. When light is absorbed by the PN junction, the energy of the absorbed photon flows to the material's electronic system in a photovoltaic cell. These have the effect of generating charge carriers, which are then separated at the junction. The power that is transformed into electricity is produced by multiplying the square of the current with the circuit resistance.

The physics underlying a PV cell are described by the corresponding circuit in Figure 2. A PV cell's output characteristics are governed by the circuit behaviour. The diode serves as a representation of the PN junction's forward biasing action. The source of the output current

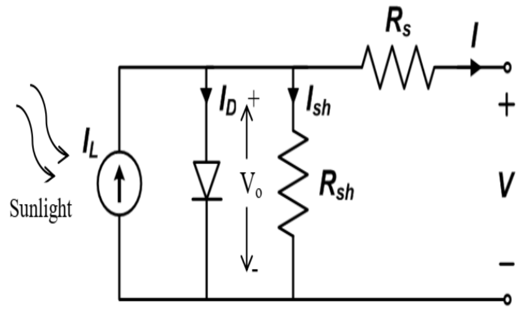


Fig. 2 Equivalent circuit of PV module

$$I = I_L - I_D - I_{sh} \quad (1)$$

$$= I_L - I_O \left[exp\left(\frac{qV_O}{nKT}\right) - 1\right] (2)$$

$$Where,\ V_0 = V + IR_s \quad (3)$$

V_0 =voltage seen across the diode.

V = voltage at load.

I_L = current generated by a photo.

R_s =The system's internal (series) resistance.

R_{sh} =Resistance to shunt

I_o = the diode's reverse saturation current. Boltzmann constant K and temperature in kelvin (1.38 x 10-23 J / K).

When the circuit is open, i.e., when I = 0, The open circuit voltage appears to be the voltage Vo across the shunt branch. I_{oc} across the output terminals.

$$V_{oc} = \frac{nKT}{q} In\left(\frac{I_L}{I_o} + 1\right) (4)$$

TABLE 1. PV MODULE ELECTRICAL CHARACTERISTICS

Parameters	Value
Average power	130 watts
Maximum power voltage (V_{mp})	17.33 V
maximum power current (I_{mp})	7.1 A
voltage on an open circuit(V_{oc})	25 V
Current in a short circuit (I_{scr})	8.5 A
Total Number of cells in the series (Ns)	36
Total number of parallel cells (Np)	2

C. Hybrid BOA with PSO

In this part, a brand-new hybrid PSOBOA that combines distinct PSO and BOA is proposed. The primary distinction How new members are accepted varies between PSO and BOA. The limitation of the PSO method to handle high-dimensional optimization in a constrained area issues is a flaw in the method.

We mix the functionality of both algorithms and do not employ both methods sequentially in order to maximize the benefits of the two algorithms. In other words, it is heterogeneous because of how the two algorithms' ultimate outputs were generated. The following is the proposed hybrid:

$$V_i^{t+1} = w.V_i^t + C_1.r_1 \times (P_{best} - X_i^t) + C_2.r_2 \times (g_{best-}X_i^t)(5)$$

where C1 = C2 = 0.5, and w can be also derived from an equation 5, r1 and r2 are the random number in (0, 1).

$$X_i^{t+1} = X_i^t + V^{t+1} \quad (6)$$

Additionally, Equations (5) and (6) can be utilised to develop a mathematical model for the basic BOA's local and global search stages. However, the global search phase of the hybrid PSOBOA can be described as follows:

$$X_i^{t+1} = w.X_i^t + (r^2 \times g_{best-}w.X_i^t) \times f_i \quad (7)$$

The hybrid PSOBOA's phase of local search can be expressed as follows:

$$X_i^{t+1} = w.X_i^t + \left(r^2 \times X_i^k - w.X_j^t\right) \times f_i \quad (8)$$

where $X_i^k$and X_j^tarej_{th} and kth butterflies selected at random from the response

The proposed HPSOBOA

This section proposes a novel hybrid HPSOBOA that combines In order to integrate the three improvement techniques' benefits suggested in this research, the cubic the PSO algorithm, BOA, and nonlinear power exponents control technique are utilized to map the initial population.

```
%_______________________________________________________________________________%

%The HPSOBOA source codes v2.0
%

%_______________________________________________________________________________%

clear

clc

close all

warning off all

 Search Agents _no = 30; % Number of search agents

Max_ iteration = 500; % Maximum number of iterations

 Function_ name='F3'; %F1-F15, US (Unimodal Separable); F16-F26, MS (Multimodal Separable)

%%% Exp2: F1, F2, F4, F6, F15, F17, F18

%US: F1, F2, F4 F6, F11, MS: F15, F17, F18, F24, F25

 %%%%% BOA in 2018

[lb,ub, dim, fobj]=Hight_ Get_ Functions _details(Function _name);

[Best_scoreBOA, Best_pos, BOA_ cg_curve]=BOA(SearchAgents_no,Max_iteration, lb,ub,dim,fobj);

 %%%% PSOBOA in 2020

[Best_score_PSOBOA,Best_pos_PSOBOA,PSOBOA_cg_curve]=PSOBOA(SearchAgents_no,Max_iteration,lb,ub,dim,fobj);

 %%%% HPSOBOA in 2020

[Best_score_HPSOBOA,Best_pos_HPSOBOA,HPSOBOA_cg_curve]=HPSOBOA(SearchAgents_no,Max_iteration,lb,ub,dim,fobj);

 %%%% plots

figure('Position',[500 400 800 200])  %[left bottom width height]

subplot(1,2,1);

func_plot_con(Function_name);

title(Function_name)

% xlabel('x_1');

% ylabel('x_2');

% zlabel([Function_name,'( x_1 , x_2 )'])

 %%%%%% Convergence curves

subplot(1,2,2);

semilogy(BOA_cg_curve,'b-','LineWidth',1)

hold on semilogy(PSOBOA_cg_curve,'g-','LineWidth',1)

hold on

semilogy(HPSOBOA_cg_curve,'r-','LineWidth',1)

 % axis tight

% grid off

xlabel('Iterations');

ylabel('Fitness value');

legend('BOA','PSOBOA','HPSOBOA')
```

D. Fuzzy Logic Control Structure

The branch of artificial intelligence (AI) that reasoning algorithms fall under is fuzzy logic. Its main objective is to imitate human decision-making and cognitive processes in machine applications. When Process data in binary form are not appropriate, fuzzy logic techniques are frequently used.

When a variable belongs to one or more sets with a specific level of membership, these sets are known as fuzzy sets serve as the foundation for fuzzy logic controller structures. The use of fuzzy logic has several advantages, including the ability to quantify inaccurate information and make decisions based on it, for as when a PV module is connected through a buck-boost dc-dc converter to a resistive load.

a. Fuzzification

Each variable used as an input or output in a fuzzy logic controller can be described using linguistic values that partition the world of discourse into adj functions. The member value indicates how much the input/output variable conversion to linguist is done.

b. Inference

The behaviour of the system's con output variables is controlleda set of guidelines. As a general rule, if x equals A, then y must be B.

When a collection of input variables is read, any rule whose premises are true to some extent is activated. This roughly modifies the control surface as a result. After that, the control surface is created after all the rules have been fired. To reflect the outcome of the constraints, as a fuzzy set, it is expressed. Inference is the name for this procedure.

c. Defuzzification

A fuzzy quantity is defuzzified, or transformed into a precise quantity. In order to defuzzify, there are numerous available techniques. The formula below illustrates the centroid technique, which is the most widely used:

$$\frac{\int(\mu(x)xdx}{\int \mu(x)dx} \quad (9)$$

where is the output x's membership degreeµ.

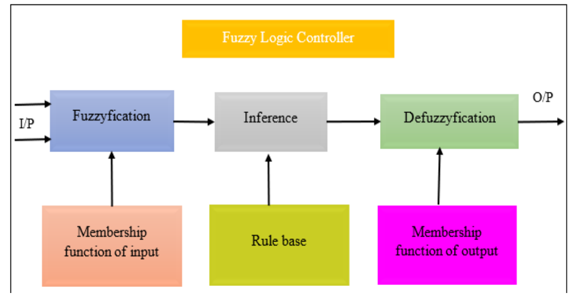


Fig .3 Fuzzy logic controller block diagram

d. Functions of theFuzzy system's membership

Fuzzy sets are used for each input and output variable.The input and output variables of the fuzzy controller were selected from Small, medium, and high are three fuzzy subsets. Due to the adoption of trapezoidal shapes for the membership duties. According to the features of the suggested PV module.The input membership ranges for PV voltage and PV current have been adjusted for the Presented in chapters two and three, respectively, were buck-boost converters. Additionally, in order to provide additional switching to give the buck-boost converter flexibility, the duty cycle—which mirrors the output of the fuzzy controller—was changed from zero to one.

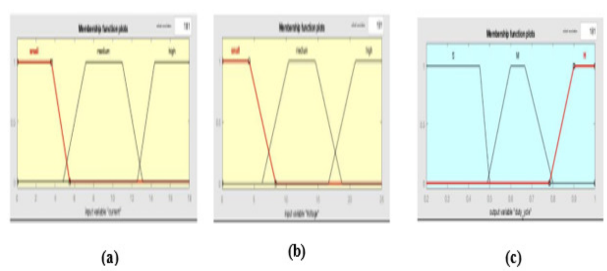


Fig 4. Membership Function of Fuzzy Logic Controller

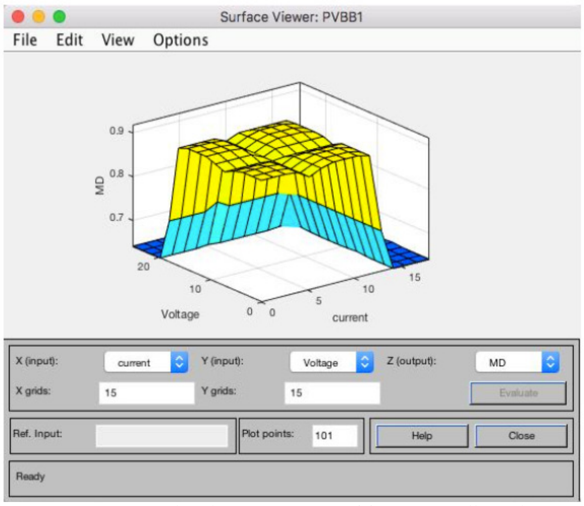


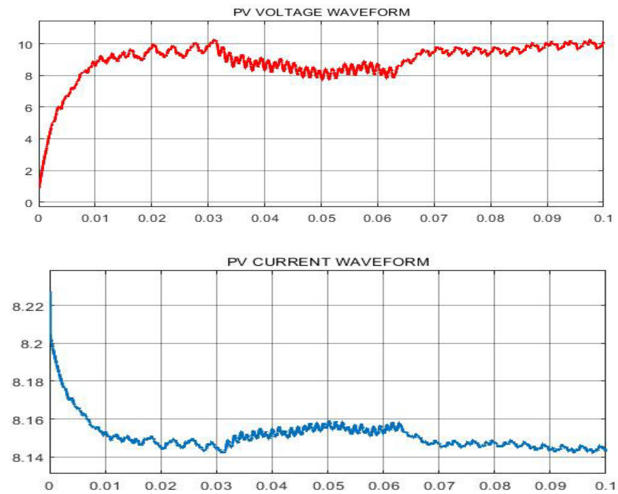
Fig.5 Graphical representation of fuzzy controller rules.

III. RESULTS AND DISCUSSION

Fuzzy sets are used for each variable's input and output. Small, medium, and high fuzzy subsets were chosen as the fuzzy controller's input and output variables. Due to the adoption of trapezoidal shapes for the membership duties. According to the features of the suggested PV module. The input membership ranges for PV voltage and PV current have been adjusted for the chapter two and chapter three presentations of the buck-boost converters. Additionally, in order to provide additional switching flexibility for the buck-boost converter, Between zero and one was the range of the duty cycle, which represents the output of the fuzzy controller.

a. PV voltage& PV current waveform

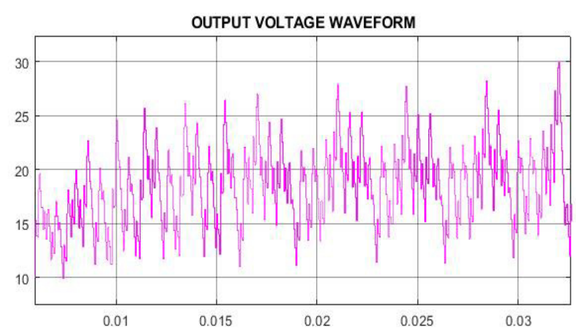
In Figure 6, The features of I-V and P-V are displayed. When using aMPPT controller with fuzzy logic, a PV module's output responses (power, voltage, and current) oscillate less than when using a PSO-based MPPT approach. By comparing Overshoot is measured as the difference between maximum power and steady state maximum power.

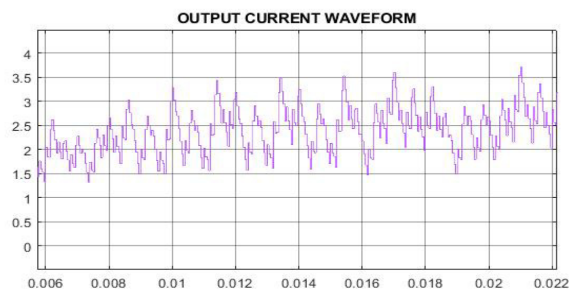


Graph.1 PV Voltage& PV Current Waveform

b. Input and output waveform

The converter's output connected to the PV array's voltage and current, the inverter's output voltage and current, the control voltage used as a switching reference, and more are also shown. in Graph.2. It is discovered that the system exhibits significant instability even as shown by the fact that the output doesn't eventually achieve a constant value after a lengthy period of time. Since the PV output is distorted and not continuous, the inverter circuit's related output waveform (current, voltage, and controller voltage) is also distorted and not sinusoidal making it easy to detect.

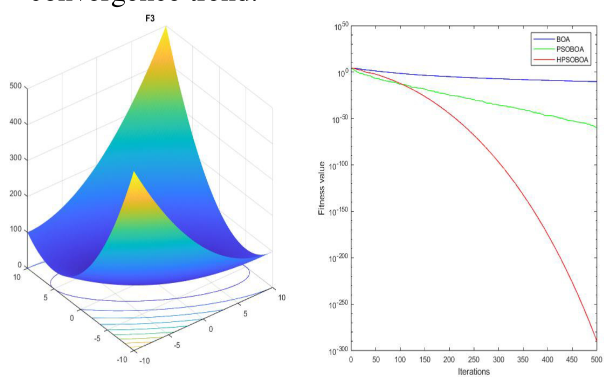




Graph 2. Output voltage & current waveform

c. HPSOBOA based Fuzzy logic control

Six high-dimensional functions from were used to generate the comparative experiment 1 with Dim = 100 and Dim = 100 for BOA [1], CBOA, PSOBOA, HPSOBOA, LBOA [5], and IBOA [9].This was done in order to evaluate the efficacy among the strategies for improvement suggested in this paper. Three multimodal problems and three unimodal problems are also present. With the exception of the function when Dim = 300, it is clear that the recommended HPSOBOA has a better convergence than the original BOA for those functions and may be able to successfully when Dim = 100, strengthen the fundamental BOA's convergence trend.



Graph 3.Output waveform of BOA, PSOBOA AND HPSOBOA

IV. CONCLUSION

The report recommends photovoltaic systems with a battery unit and a two-stage converter. The suggested control method is FLC control based on hybrid algorithms.There is also a control for the bidirectional converter. The combined control was able to track successfully under a variety of irradiation settings thanks to the rapid and responsive control capabilities of the suggested technique. The bidirectional battery technique shows that battery modes can be controlled more effectively,along with the advantages for the overall system and the results of the combined control performance tests. The effectiveness of the MPPT control was looked into. The MPPT system has a control effectiveness of 9.5%. The experiment showed that an increase in inertia considerably improves the frequency dynamics. This shows that FLC can use the Two-Stage Simulink model effectively and accurately. The research suggests two-stage converter photovoltaic systems with a battery unit. The hybrid algorithms-based FLC control is the proposed control technique. There is also a control for the bidirectional converter. The proposed approach's quick and responsive control capabilities allowed the combined control to track successfully under a variety of irradiation conditions. In addition to having a favourable impact the bidirectional battery technique demonstrates that controlling battery modes also has a higher control capacity on the overall system and passes the combined control performance tests. The effectiveness of the MPPT control was looked into. The MPPT system has a control effectiveness of 9.5%. The experiment showed that an increase in inertia considerably improves the frequency dynamics. This shows that FLC can use the Two-Stage Simulink model effectively and accurately.

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