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ORIGINAL RESEARCH

Designing an empirical grid-connected PV system based on FLC-MPPT approach for local community use

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Abstract
Photovoltaic (PV) systems play a vital role in mitigating renewable energy issues ranging from the oil crisis to environmental concerns. The given paper proposes a grid-connected PV power system with high voltage gain (VG) and a high-speed multiphase buck-boost converter. With this converter, PV panels can be integrated in any fashion as per varying climatic conditions without affecting the switching stress. Also, the proposed system makes use of maximum power point tracking (MPPT) concept with fuzzy logic control (FLC) algorithm in order to reduce losses and complexities associated with the system. For validation of the system, an annual dataset related to global solar irradiance across three locations in Tamil Nadu is taken into consideration. The proposed system is validated and compared with traditional MPPT methods based on power output (W) and energy efficiency (%). It includes the computation of predicted mean (PM) values and comparing them with actual mean (AM) values of solar radiation for each of the locations. The results show a good correlation between the predicted and actual values and higher efficiency, thereby making the proposed system suitable for forecasting solar irradiance.

Keywords Solar irradiance · Energy efficiency · PV system · MPPT · Utility grid · FLC

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1 Introduction

Today, photovoltaic (PV) systems are gaining popularity due to rising energy demand across the globe. Existing PV system variants are there for tracking solar energy radiation, such as centralized inverter systems, string inverter systems, module-integrated systems, and many more [1–3]. However, they are not feasible due to the complex structure, lack of solar irradiance data, higher maintenance costs in maintaining equipment, etc. The solar radiation intensity or irradiance at any location depends on changes in various parameters such as hour angle, climatic conditions, longitude, latitude, pressure, and temperature [4, 5]. Thus, it becomes mandatory to analyze meteorological parameters affecting global solar irradiance. The solar radiation captured by existing PV systems causes fluctuations in PV array voltage with very high power, thereby leading to distortion in the system. Such systems are not suitable for module-integrated inverters because of the fixed power rating of modules such as 500 Watts [6, 7]. In general, the PV system separates voltage and current from the battery load in order to extract the maximum power of the PV module. This process is known as maximum power point tracking (MPPT) [8]. There are several existing conventional algorithms for making use of MPPT in PV systems, such as Incremental Conductance (IC) [9], Perturbation and Observation (P&O) [10], and Ripple Correlation Control (RCC) [11], but they failed to meet the requirements of varying environmental conditions. The issues with these existing algorithms are higher costs, complexity, and risk of losing power; irregular fluctuations in current-voltage output; noisy phase loads; and instability. It also needs a larger inductor to decrease the fluctuation of the voltage and power. To overcome aforementioned issues with conventional MPPT techniques, we have used the concept of FLC which is suitable to achieve maximum power for PV systems due to its robustness and higher stability. Use of FLC is preferred because it can be applied for handling non-linearity and enhancing battery life. The given paper holds the following novel contributions:

- A grid connected PV power system is designed with an intention to maximize power performance equipped with interleaved boost converter.
- This high multiphase buck-boost converter produces higher voltage gain (VG) by reducing fluctuations and lowering voltage stress.
- The proposed design uses MPPT method which produces high power output by lowering the number of PV cells thereby reducing the overall cost of the system.
- In addition to this, FLC is used which can easily handle non-linearity conditions as well as varying climatic conditions or irradiance level.
- The proposed system is designed with higher efficiency to ensure feasibility for real-time implementation thus surpassing existing traditional MPPT studies.

1.1 Organization of the study

The given paper is organized into the following sections. Section 2 presents an overview of recent cited works in the context of features associated existing MPPT techniques used for forecasting solar irradiance. Section 3 presents the proposed design based on FLC-MPPT technique. Section 4 shows results and discussions. Section 5 provides conclusion and future scope followed by references.

2 Related works

Table 1 presents a comparative analysis of existing works in the context of PV systems used for forecasting of solar irradiance.

3 MPPT-FLC approach

Figure 1 shows the block diagram of the proposed system. Its phases are described as follows:

3.1 PV array description

A typical PV array used by dc to dc converters to maintain maximum output generated by solar cells is shown in Fig. 2. PV array is a set of solar cells and controller interconnected in both directions to produce energy (E). The controller used here is fuzzy MPPT controller which computes the power (P) based on maximum current (I_m) and maximum voltage (V_m) input values. The basic principle of our proposed approach is examination of P in each time frame and then defining the change in power with respect to voltage ($\phi P / \phi V$).

Rule 1: If $(\phi P / \phi V) > 0$, then FLC modifies duty cycle (D) to increase voltage until $(\phi P / \phi V) = 0$.

Rule 2: If $(\phi P / \phi V) < 0$, then FLC changes duty cycle (D) to reduce voltage until $(\phi P / \phi V) = 0$.

FLC is used here because it does not need any complex calculations for producing maximum power (P_m) from PV modules. It can easily work in varying climatic conditions such as change in irradiation or temperature level.

3.2 Buck boost converter

Boost converters are used to raise the output voltages of PV modules up to the required level. Energy is stored in

Table 1 Comparison of existing works with proposed approach

Existing works/ Proposed	High voltage gain	Can be applied to string/multi module inverter system	Handles varying climatic conditions	Stabilization of dc bus voltage	Maximum power transfer	Multiphase Buck-boost converter	FLC-MPPT
[12]	✓	✓		✓			
[13]	✓			✓	✓		
[14]		✓	✓		✓		
[15]		✓	✓	✓			
[16]	✓			✓			
[17]	✓	✓		✓			
[18]	✓	✓		✓	✓		
[19]	✓		✓		✓	✓	
[20]				✓		✓	
[21]	✓				✓		✓
[22]		✓	✓		✓		✓
[23]	✓		✓	✓			
[24]	✓			✓			
[25]		✓	✓				
[26]			✓		✓		
[27]	✓	✓	✓	✓			
Proposed	✓	✓	✓	✓	✓	✓	✓

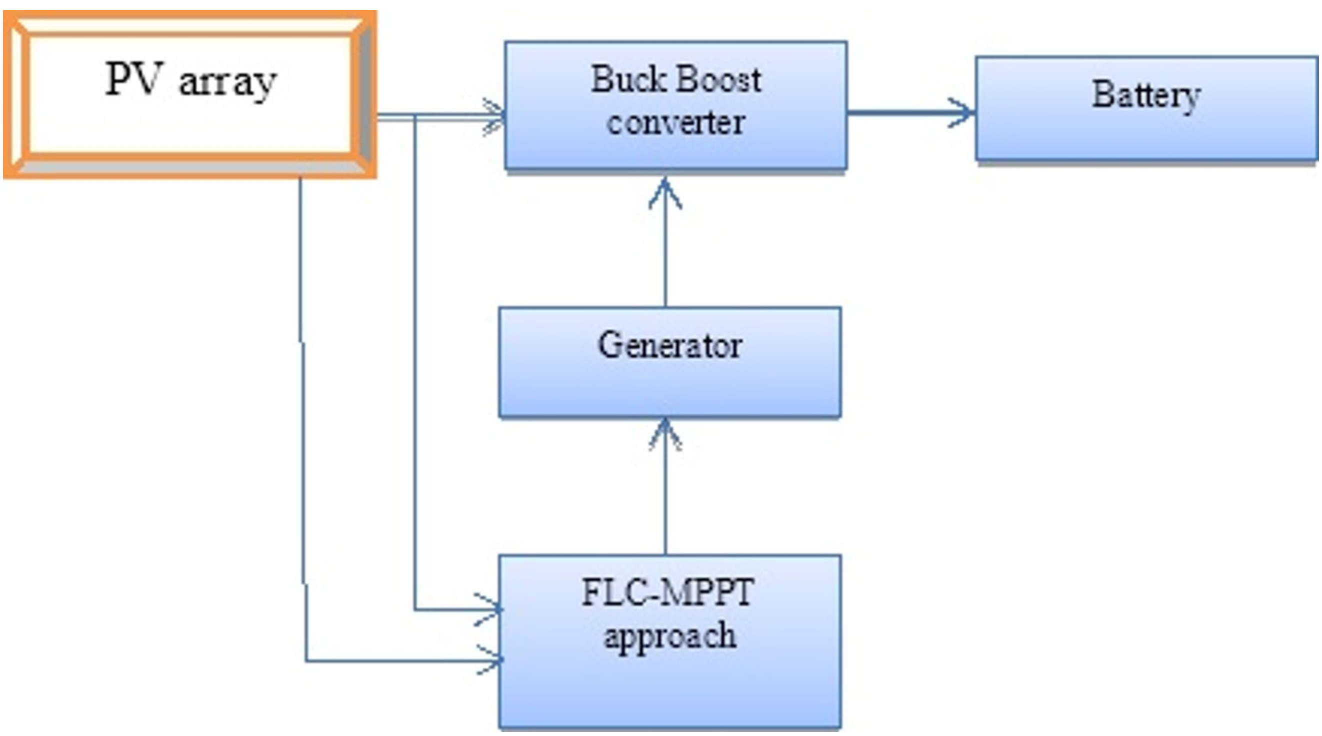

Fig. 1 Block diagram of the proposed framework

inductance (L) while the current (I) flows through it. Capacitor (C) is present to provide suitable load. The current flowing through L charges the C and feeds the load during duty cycle (D). Figure 3 shows the circuit diagram of buck boost converter.

3.3 Generator

After monitoring PV current and voltage during duty cycle, it is sent to the generator which boosts regular operation to ensure working of PV array. The use of FLC-MPPT helps in adapting varying weather conditions so that the proposed system remains efficient under fluctuating solar irradiance.

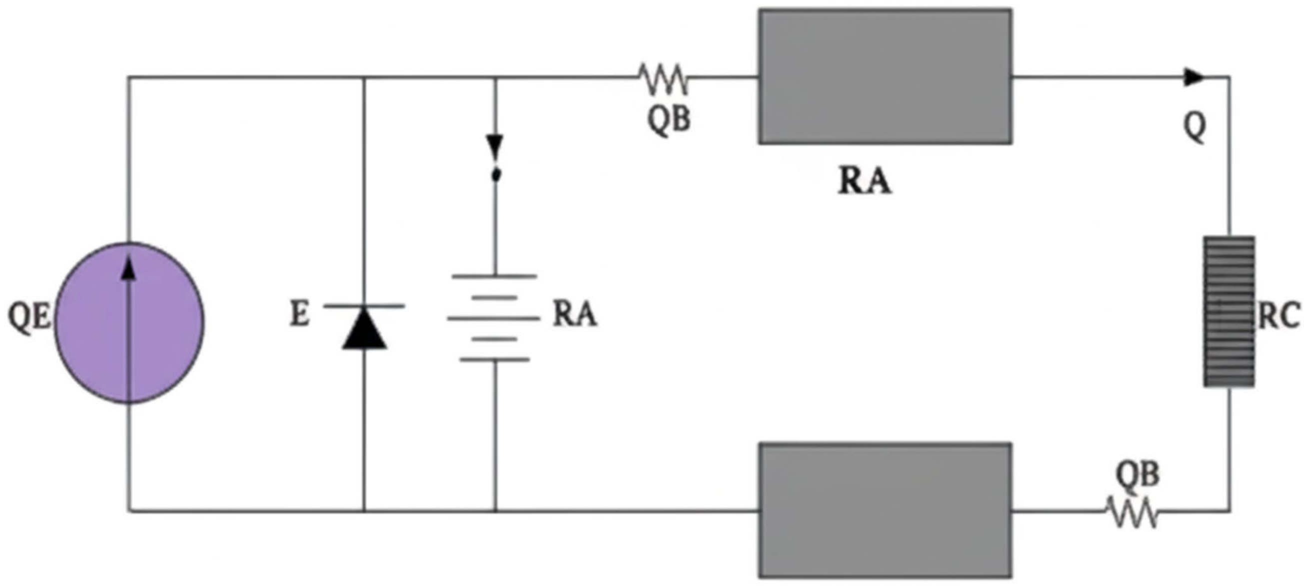

Fig. 2 A typical PV array (Q represents charges while R represents connected resistances)

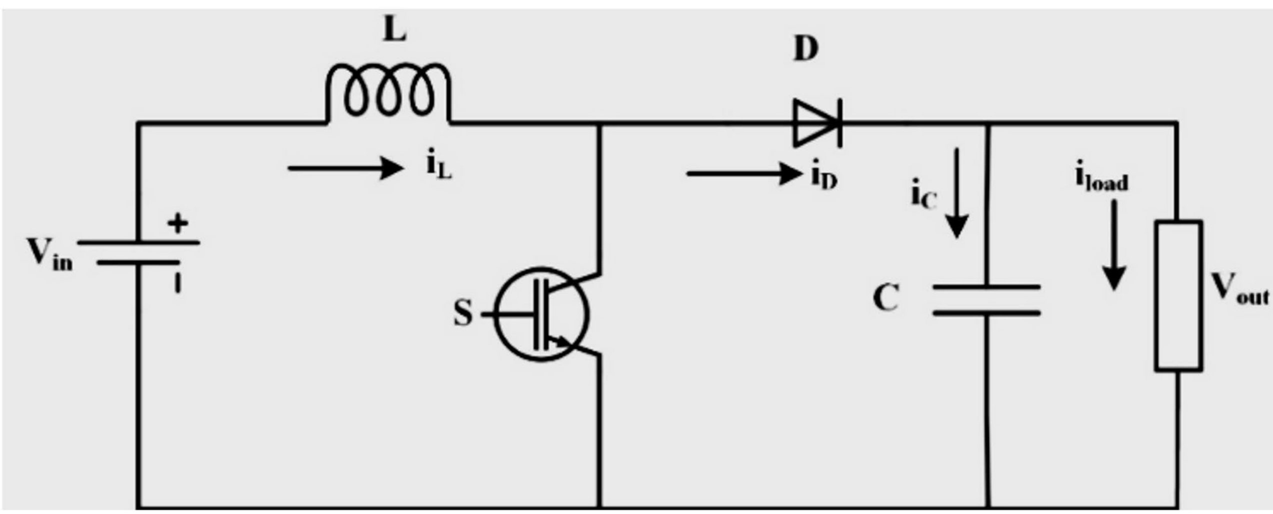

Fig. 3 Buck boos converter circuit [28]

3.4 FLC-MPPT approach

It involves two phases-fuzzification and rule evaluation in order to reduce losses and complexities associated with the system.

In this process, the input variables i.e. change in voltage (ϕV) and change in power values (ϕP) are transformed into fuzzy inputs using membership functions generated by Sugeno fuzzy inference system (FIS) [29]. The output variable i.e. power (P) has two linear membership functions lying in the range of [-1, 1]. Figure 4 shows plot of membership functions.

3.5 Rule evaluation/ Inference Engine

Sugeno's method [28], which implements a rule to the fuzzy input, is used to determine the FIS. This phase involves fuzzy processor for determination of lingual rules. These rules are used to monitor the DC to DC converter and ensure that the PV module's MPP is met. The control rules are interpreted as:

- If ϕV is large negative and ϕP is large positive, then output is D1.
- If ϕV is small negative and ϕP is small positive, then output is D2.

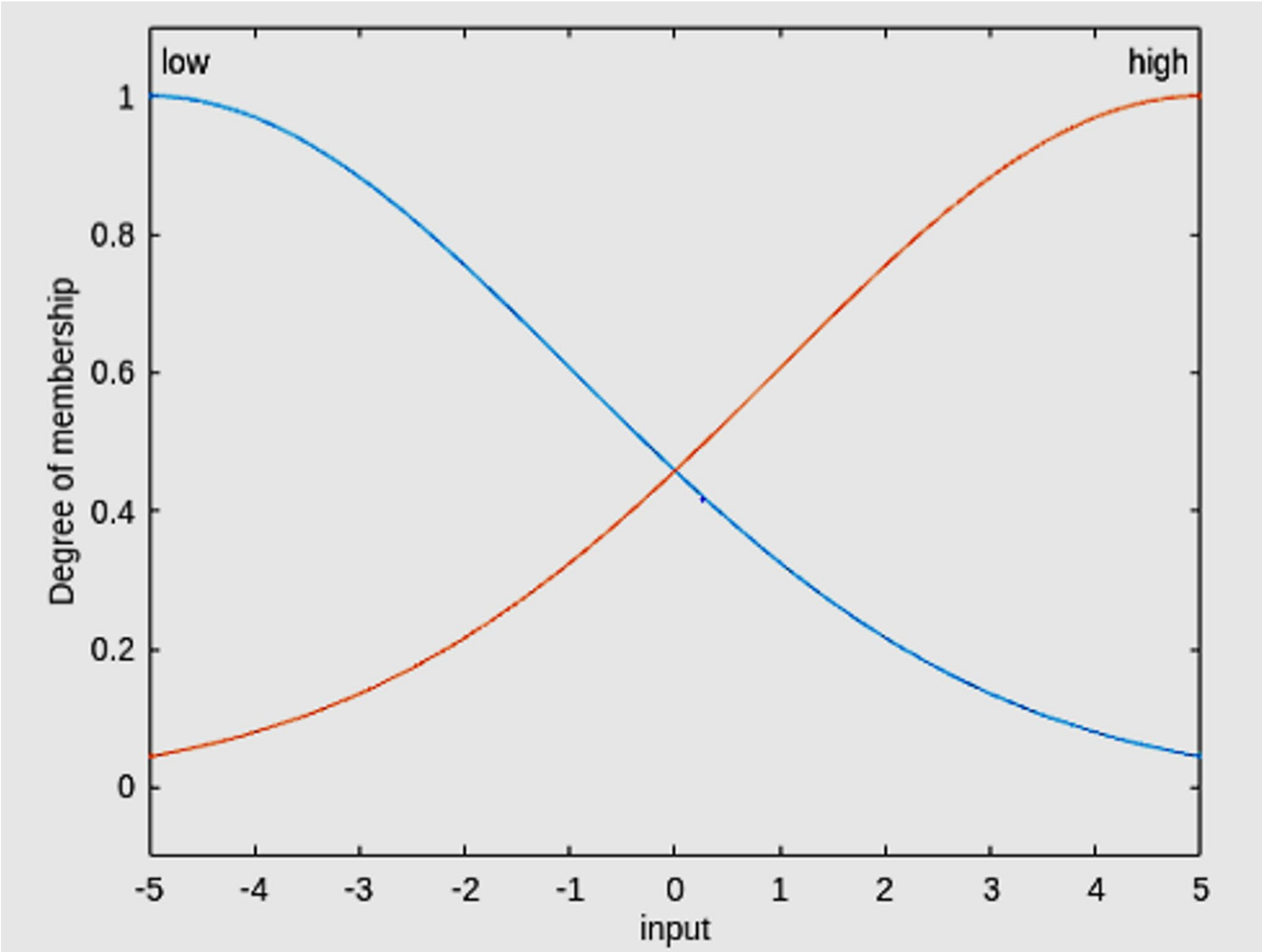

Fig. 4 Membership functions plot

Table 2 Simulation parameters and specifications

Parameters	Values
Maximum voltage (V_m)	25 V
Maximum current (I_m)	6.25 A
Maximum power (Watt)	200 W
No. of series connection	1
Inductance coil (L)	1.121
Nominal voltage (V_n)	50 V
Battery prompt time	40 s
Switching frequency (KHz)	10

- If ϕV is medium negative and ϕP is medium positive, then output is D3.

4 Simulation and results

The results are produced based on varying irradiance and varying temperature by taking global solar irradiance annual dataset [29] into consideration. The data are in kW-hr/m^2/day, and are aggregated by month. The annual mean is also calculated. The data were prepared using NASA POWER. The data are useful for a variety of applications, including solar energy research, solar energy project planning, and solar energy education. Table 2 mentions simulation parameters used for simulating the proposed system.

4.1 Results under varying irradiance

Figure 5 shows assessment and validation of the proposed system with existing studies [12–27] based on irradiation factor (W/m^2). Here irradiation is selected at 1000 W/m^2. The results show that the proposed system attains the maximum output (**235.67 W**) thus surpassing existing approaches and studies. It proves to be robust framework for delivering optimal results across all situations.

Similarly, at 1000 W/m^2 irradiation level, the proposed system attains the highest energy efficiency **(98.56%)** as compared to existing works.

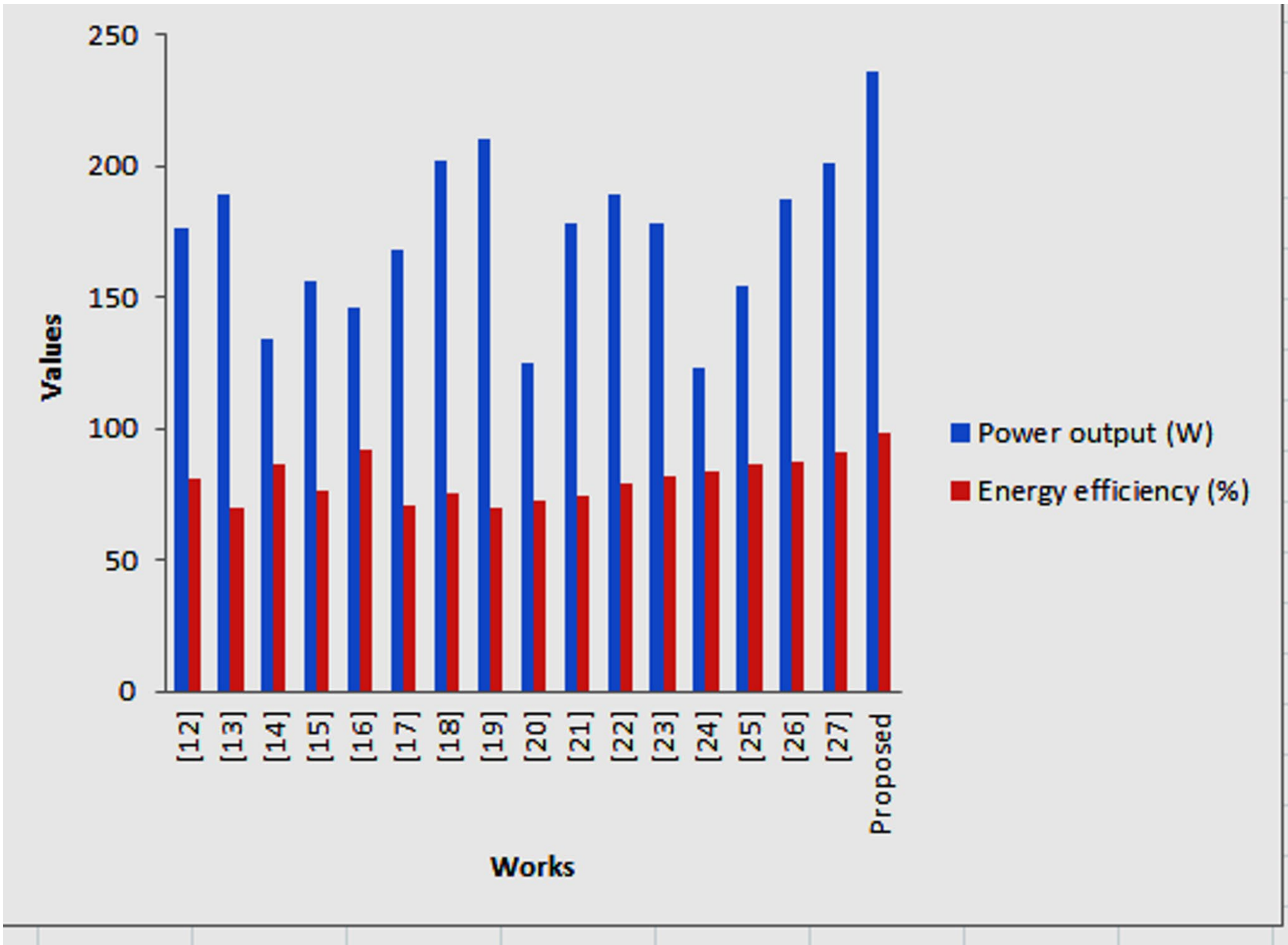

Fig. 5 Validation of the proposed system (varying irradiance)

4.1.1 Case 2: results under varying temperature

Figure 6 shows assessment and validation of the proposed system with existing studies [12–27] based on temperature (Celsius). Here irradiation is selected at 25 °C. The results show that the proposed system attains the maximum output (**220.12 W**) thus surpassing existing approaches and studies. Similarly, at 25 °C, the proposed system attains the highest energy efficiency (**97.13%)** as compared to existing works.

5 Conclusion and future scope

The given paper proposes a grid-connected PV power system with high voltage gain (VG) and a high-speed multi-phase buck-boost converter. With this converter, PV panels can be integrated in any fashion as per varying climatic conditions without affecting the switching stress. Also, the proposed system makes use of maximum power point tracking (MPPT) concept with fuzzy logic control (FLC) algorithm in order to reduce losses and complexities associated with the system. This paper studies the evaluation of the production of electricity by the direct transformation photovoltaic cells, using a semi-empirical model in order to estimate the solar radiation value according to atmospheric parameters. The energy supplied by the photovoltaic cell being in direct current, it must be stabilized before any use because it is affected by the variation of the atmospheric conditions, for the receivers operating in alternating current, the use of an inverter is essential. During the most unfavourable periods or at night, the use of storage batteries is necessary for a permanent supply. The performance of the proposed system is assessed and validated based on metrics such as power output (W) and energy efficiency (%). The results are promising thus attaining the highest output (235.67 W) and highest energy efficiency (98.56%) in case of varying irradiance. Similarly, at varying temperature, the system attains the power output of 220.12 W and 97.13% energy efficiency.

In addition, in order to guarantee the protection and operation of the tank storage battery, the presence of the

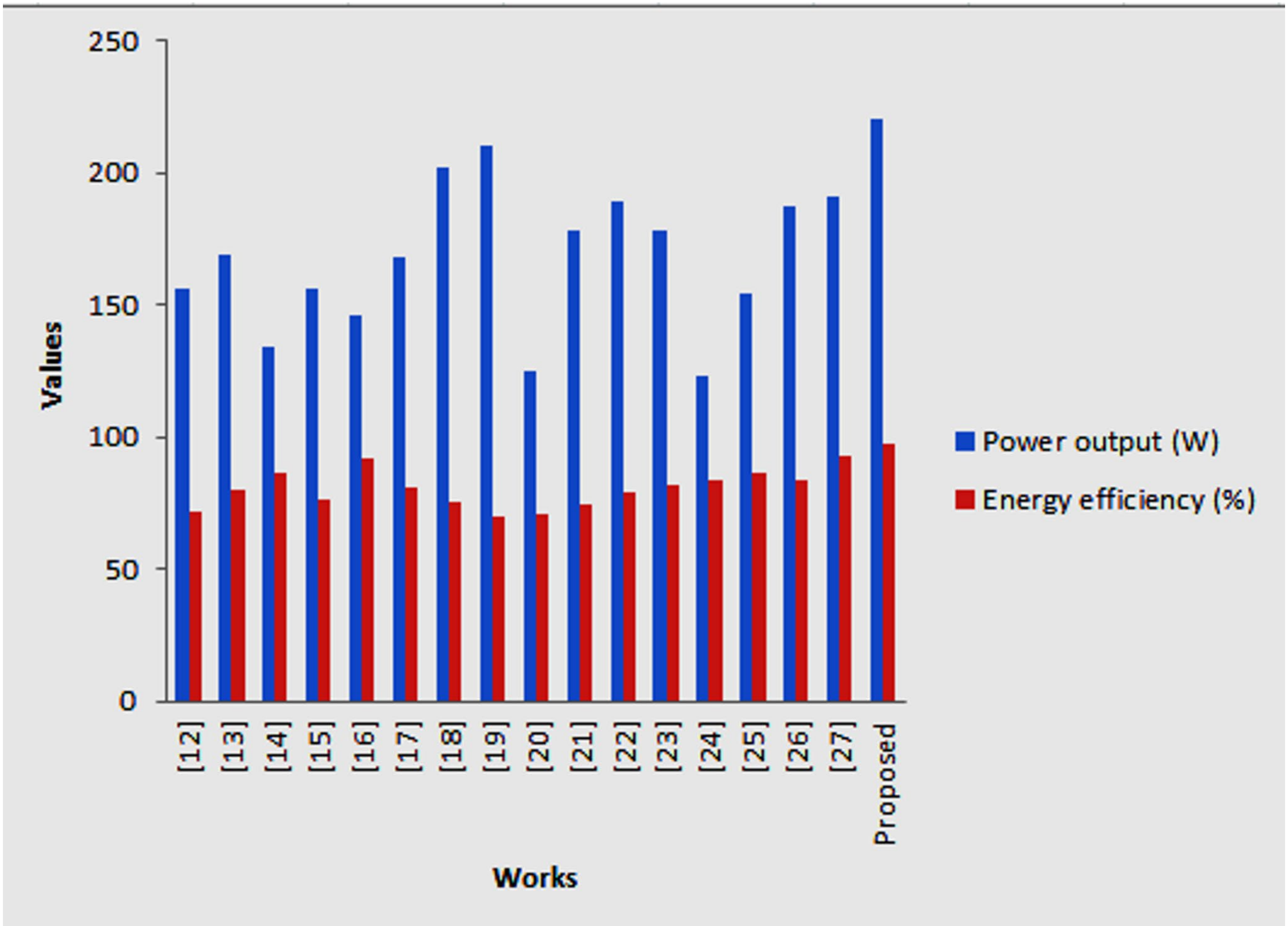

Fig. 6 Validation of the proposed system (varying temperature)

compatible charge regulator is necessary. The connection cables between the different main components of the photovoltaic system must be sized and adapted respecting sections presenting an admissible current for reasons of safety and energy efficiency.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest to report regarding the present study.

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