



Qudwa optimizer: A Muslim spiritually inspired metaheuristic for improved PV MPPT – A comparative study with IT2FL

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ABSTRACT

This paper introduces the Qudwa Optimizer (QO), a novel metaheuristic algorithm inspired by Islamic spiritual principles, designed to overcome to enhance PV MPPT through three core mechanisms: (1) Qudwa (guided exploration), (2) Ibada (worship-based exploitation), and (3) Ilm (knowledge-driven diversification). The method incorporates a unique anti-local convergence mechanism (metaphorically termed "Satanic Repulsion") to escape suboptimal solutions. We apply Qudwa Optimizer to PV MPPT and rigorously compare its performance against Interval Type 2 Fuzzy Logic (IT2FL). Simulation results demonstrate that Qudwa Optimizer based PV MPPT outperforms both P&O and IT2FL based PV MPPT. Qudwa Optimizer achieves higher efficiency than IT2FL with 0% of overshoot and 0.0421s of settling time, while maintaining superior stability. The algorithm's ability to balance exploration and exploitation makes it a promising alternative to existing AI and swarm-based MPPT techniques.

1. INTRODUCTION

Solar photovoltaic (PV) systems are crucial for green energy due to their ability to generate electricity from sunlight without producing harmful greenhouse gas emissions. This makes them a sustainable alternative to fossil fuels, helping to reduce our reliance on non-renewable energy sources and mitigate climate change. Solar PV also contributes to energy independence, cost savings through reduced electricity bills, and potentially increased property values. Photovoltaic (PV) energy, while considered green, faces several constraints. These include the intermittency of solar power, requiring energy storage or grid backup; high initial installation costs; land use conflicts and environmental impacts; and challenges related to grid integration. Maximum Power Point Tracking (MPPT) (Endiz et al., 2025; Kathe et al (2023); Vaikundaselvan et al., 2020; Ahmed et al., 2022; Sarvi & Azadian, 2022; Baba et al. 2020; Ali et al. 2023; Hanzaei et al., 2020) is a technique used in photovoltaic (PV) systems to

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maximize the power output of solar panels by continuously adjusting. The operating conditions to match the maximum power point (MPP) on the panel's voltage-current curve. Essentially, it ensures the solar panel operates at the voltage and current that delivers the highest power output, regardless of changing sunlight intensity or temperature. MPPT is critical for optimizing photovoltaic (PV) system efficiency, yet conventional approaches struggle under partial shading and rapidly changing environmental conditions. While computational intelligence techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS) (Chou et al., 2020), IT2FL (Magaji et al., 2022), and metaheuristics such as the Grey Wolf Optimizer (GWO) (Sang-To et al., 2022; Long & Xu, 2017; Song et al., 2015; Mirjalili et al., 2014) have shown promise, they suffer from fundamental limitations. The rest of this paper is organized as follows: Section 2 Methodology, Section 3 PV modelling, Section 4 details Qudwa's algorithm design, Section 5 validates its MPPT performance, and Section 6 concludes with future directions.

2. METODOLOGY

This paper introduces Qudwa Optimizer, the first metaheuristic algorithm grounded in Islamic spiritual principles, offering a novel framework to address these challenges. The methodology translates three core concepts into optimization mechanics:

- Qudwa: Guided global exploration, emulating the pursuit of exemplary models
- Ibada: Local intensification through iterative "worship" of high-quality solutions.
- Ilm: Knowledge-driven diversification via stochastic learning.

A unique "Satanic Repulsion" operator (metaphorically named) actively repels particles from suboptimal regions, countering greed-inspired stagnation seen in GWO/PSO. By embedding spiritual equilibrium into its search process, Qudwa achieves:

- Adaptive exploration-exploitation balance via dynamic Ilm (Knowledge) - Ibada (Worship) weights.
- Guaranteed convergence through Qudwa-attraction to global best solutions.

This study introduces the first Muslim spirituality-based metaheuristic for engineering optimization, rigorously benchmarks the Qudwa Optimizer against IT2FL in PV MPPT, and demonstrates its higher efficiency than both P&O and IT2FL-based PV MPPT approaches.

3. PV MODELLING

The solar system under consideration, depicted in Fig. 1. The single-diode model is depicted in Fig. 2.

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_s \times \left[\exp \left(\frac{q(V + IR_s)}{k_c A} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (1)$$

$$I = [I_{sc} + K_1(T_c - T_r)]\lambda$$

where, I_{ph} : photocurrent current, I_D : diode current, I : output current from the cell, I_{sh} : shunt resistor current, I_s : diode saturation current, K_1 : Boltzmann constant, q : electron charge, T_c : actual cell temperature, R_{sh} : shunt resistance, and I_{sc} : short-circuit current, T_r : reference temperature, λ : irradiance

and R_s : series resistance, V and I are the output voltage and output current of the PV module respectively. The Table 1 summarizes the PV module electrical characteristic values.

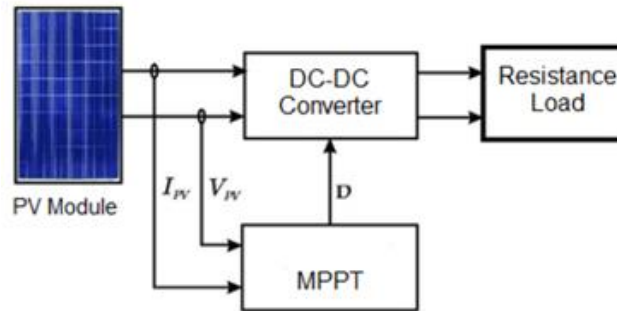


Fig 1. Schematic diagram of the proposed system.

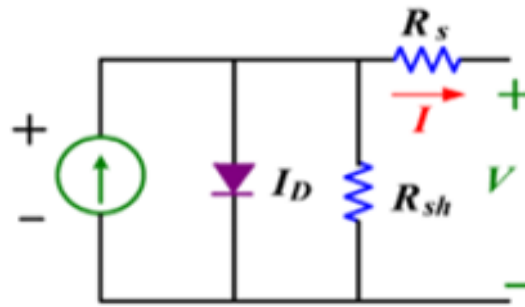


Fig 2. PV cell equivalent circuit

Table 1. PV module electrical characteristic values

Electrical characteristic	Value
Power at maximum power point (Pmpp) W	200.143
Voltage at maximum power point (Vmpp) V	28.7
Current at maximum power point (Impp) A	7.61
Open Circuit Voltage (Voc) V	32.9
Short Circuit Current (Isc) A	8.21
Number of cells connected in series	54
Number of cells connected in parallel	1

4. PV MPPT APPLICATIONS

PV MPPT is an essential controller for optimizing the performance of a photovoltaic system. To overcome the limitations of existing methods while enhancing MPP efficiency, we introduce a novel intelligent MPPT algorithm inspired by Islamic spiritual principles. Its detailed implementation is presented below:

4.1 Qudwa optimizer algorithm design

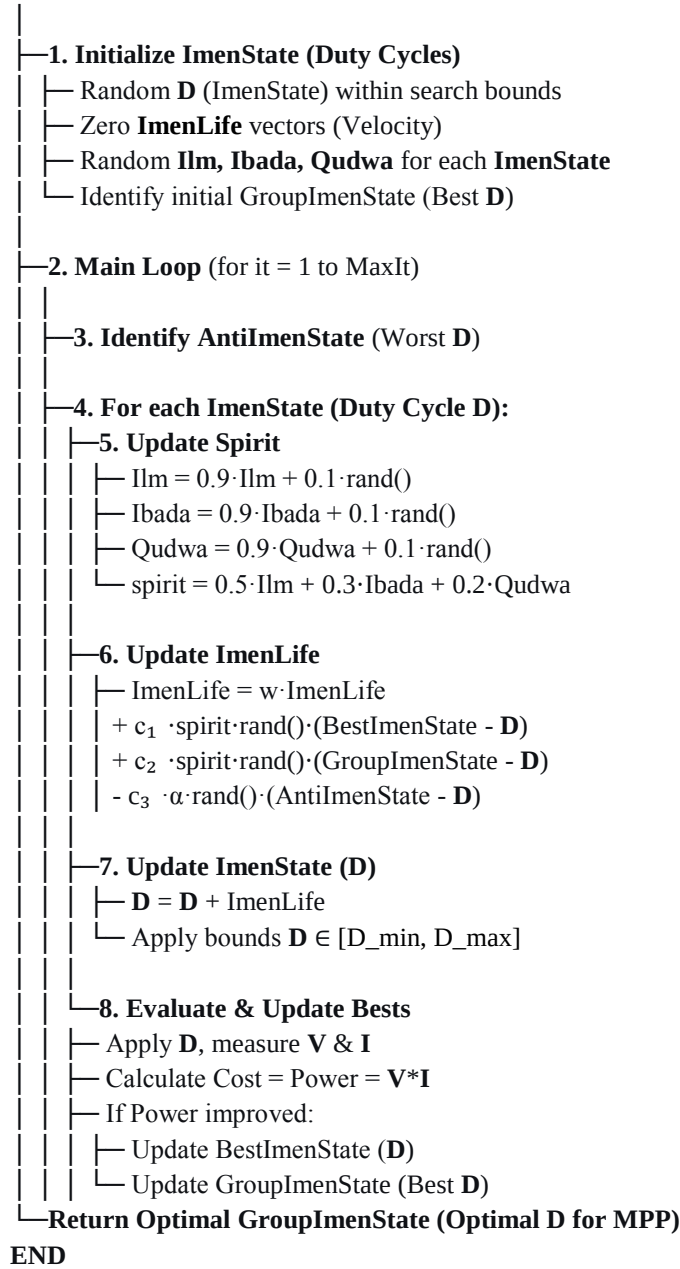
Qudwa Optimizer, a novel metaheuristic algorithm inspired by Islamic spiritual principles, designed to address the common limitations of premature convergence and poor exploration-exploitation balance in existing approaches like PSO and GWO. In the Holy Quran, 'Qudwa' refers to individuals whom others

imitate because of their behavior, worship, and qualities. The algorithm incorporates three core concepts:

- (i) Qudwa (guidance) for guided exploration,
- (ii) Ibada (worship) for local intensification through optimization processes,
- (iii) Ilm (knowledge) for solution diversification.

The method introduces a unique anti-local convergence mechanism featuring a stochastic repulsion function (metaphorically representing "Satan") to avoid suboptimal regions. Our hybrid approach combines gravitational movement for balanced search with a "repentance" operator for solution correction. The flow diagram is below:

START Qudwa PV MPPT



4.2 P&O based PV MPPT

The PV MPPT P&O is implemented according to the algorithm below:

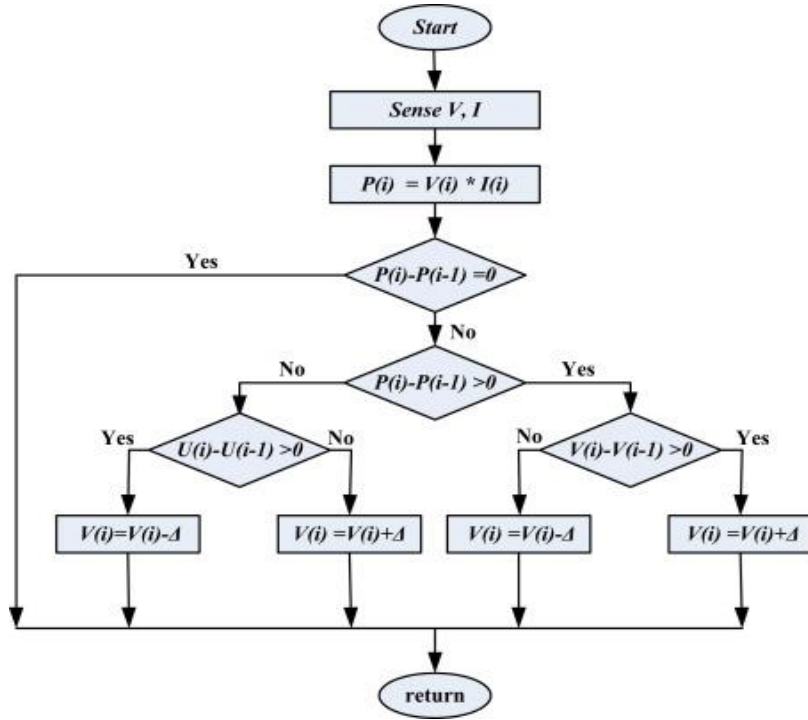


Fig 3. Flowchart of P&O MPPT algorithm

4.3 PV MPPT based IT2FL

Fuzzy logic possesses the unique capability to navigate the subtleties and complexities inherent in real world. Type 2 fuzzy sets provide greater flexibility compared to Type 1 sets by incorporating an additional degree of freedom in the fuzzy inference process. This feature makes them particularly effective in environments with uncertainty and ambiguity, thereby enhancing system performance. An Interval Type 2 Fuzzy Set (IT2FS) $\tilde{A}$ is characterized by a membership interval in the universe of discourse X as:

$$\tilde{A} = \{(x, u), \mu_{\tilde{A}}(x, u) | \forall x \in X, \forall u \in J_x \subseteq [0, 1]\} \quad (2)$$

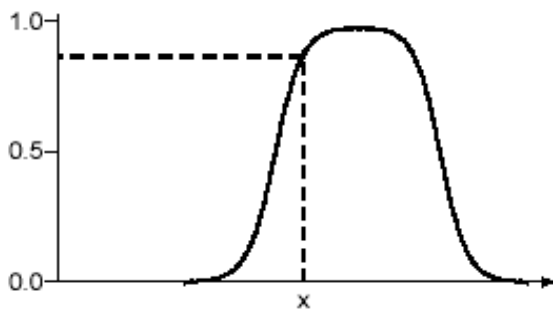


Fig 4. Membership function of fuzzy logic type 1

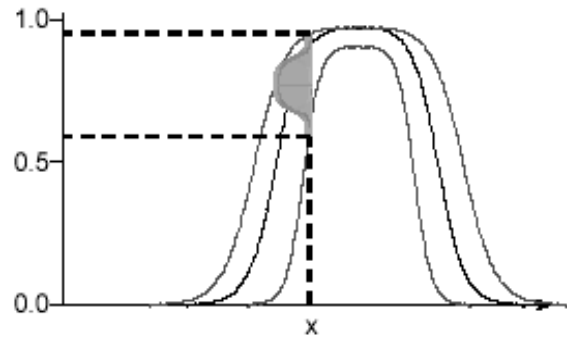


Fig 5. Membership function of fuzzy logic type 2

Illustrated in Fig. 6, the architecture of the proposed IT2FL controller includes the following essential components: a fuzzifier, an inference engine, a fuzzy rule base, and an output processor that integrates both a type-reducer and a defuzzifier.

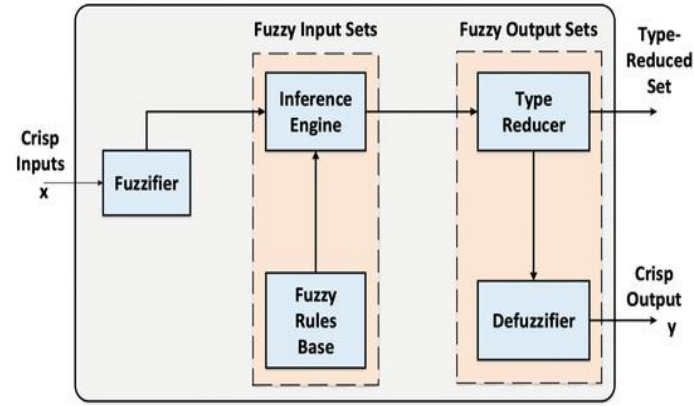


Fig 6. Main components of Type 2 controller

5. SIMULATION AND DISCUSSION

The Qudwa Optimizer's performance was rigorously evaluated against the IT2FL and P&O) in PV MPPT. The simulated system is depicted below:

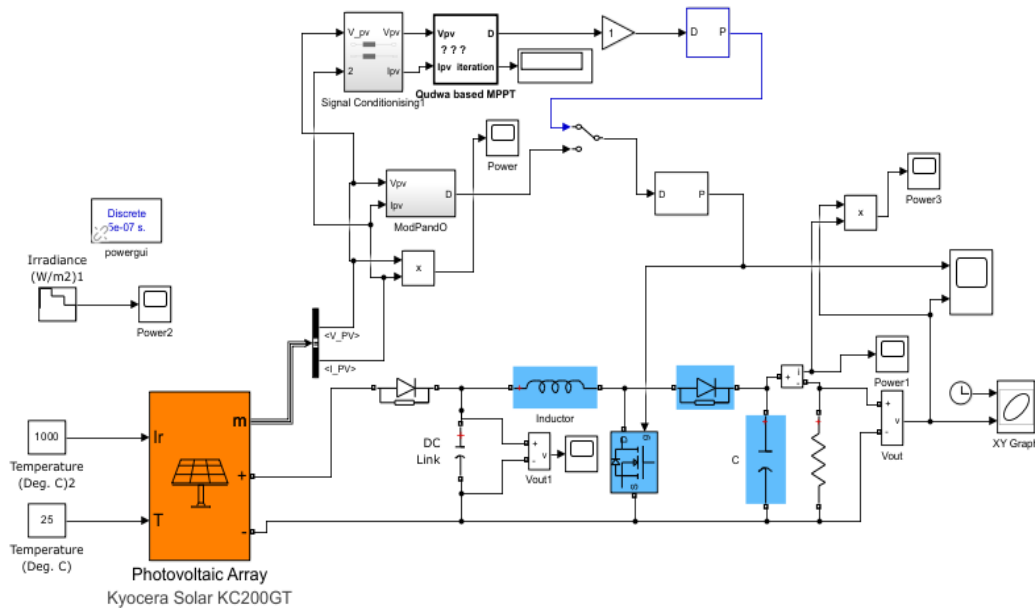


Fig 7. Simulated system under Simulink

Fig. 8 shows the membership functions of IT2FL based PV MPPT controller with the parameters below:

- Type Reduction Method = "karnikmendel"
- LowerScale = 0.6
- LowerLag = 0.4

The performances of PV MPPT systems presented in Figs. 9-11 are summarized in Table 2. QO demonstrates a balanced performance:

- Moderate rise time (0.0278 s),
- Zero overshoot (0%), significantly lower than IT2FL,

- 0.0421 s Settling time, while P&O, and IT2FL do not have one,
- Maximum power compared to the other algorithms,

Table 2. PV MPPT comparison results

	P&O	IT2FL	QO
RiseTime	0.0165	0.0179	0.0278
SettlingTime	-	-	0.0421
SettlingMin	180.0017	180.0026	180.0003
SettlingMax	200.1374	200.1368	199.5011
Overshoot	0.0687	0.0684	0
Undershoot	0	0	0
Peak	200.1374	200.1368	199.5011
PeakTime	0.0245	0.0293	0.0722

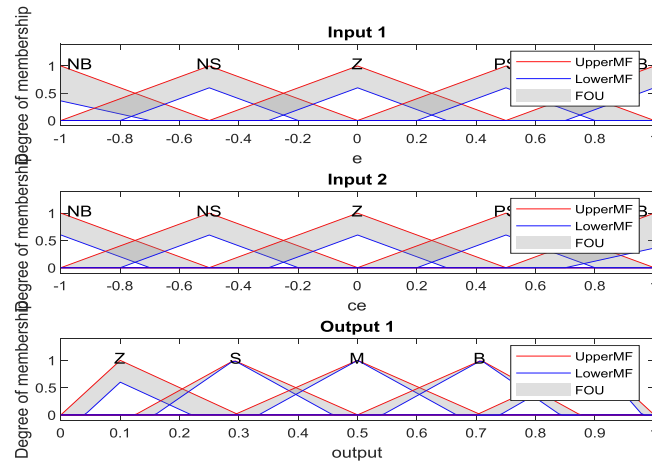


Fig 8. Membership functions of IT2FL based PV MPPT controller

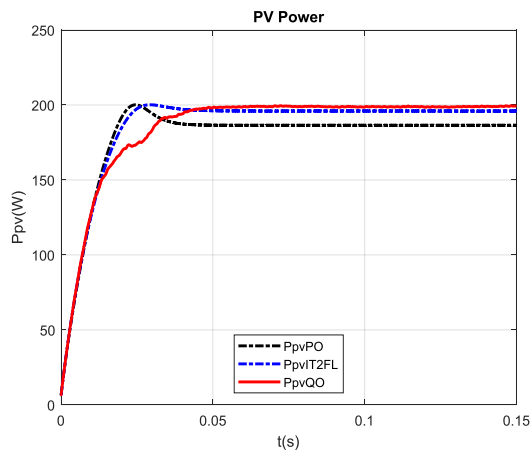


Fig 9. Comparative analysis of PV power output using P&O, IT2FL, and QO-based MPPT controllers

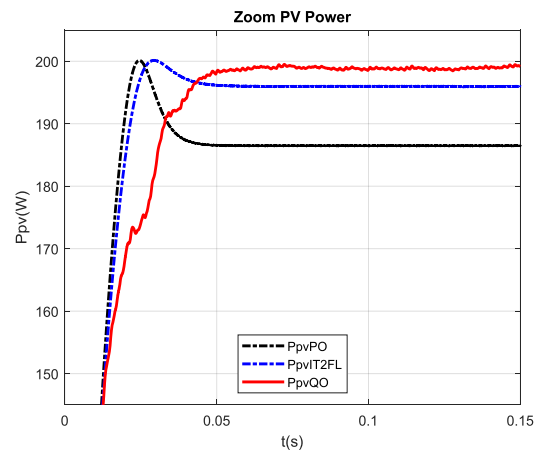


Fig 10. Zoom of comparative analysis of PV power output using P&O, IT2FL, and QO-based MPPT controllers



Fig 11. Comparative analysis of Load power using P&O, IT2FL, and QO-based MPPT controllers

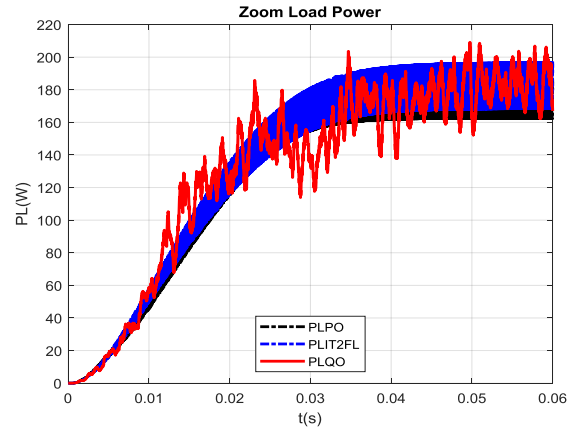


Fig 12. Zoom of comparative analysis of Load power using P&O, IT2FL, and QO-based MPPT controllers

5. CONCLUSION

The Qudwa Optimizer outperforms both P&O and IT2FL in key performance metrics, particularly in overshoot, and settling time control, and power tracking accuracy. It offers a well-balanced trade-off between the stability and maximum power compared to P&O and IT2FL, making it a promising and intelligent MPPT solution for advanced photovoltaic energy systems.

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