



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 15, Issue 4, April 2026

GWO and MPPT Based Modified PV System Configuration for under Mismatch Conditions

Shalini M, Prof. N. Navaneethan,ME.,

Department of Power Electronics and Drives, AVS Engineering College, Military Road, Ammapet, Salem,
Tamil Nadu, India

Department of Electrical and Electronics Engineering, AVS Engineering College, Military Road, Ammapet
Salem, Tamil Nadu, India

ABSTRACT: Photovoltaic (PV) systems experience significant power losses under partial shading conditions (PSCs) due to mismatched module outputs, limiting maximum power extraction. To address this issue, a hybrid maximum power point tracking (MPPT) algorithm, artificial neural network–Grey wolf optimization (ANN–GWO), is introduced, combining ANNs and GWOs. ANN reduces tracking time to approximately 0.02 seconds during rapid weather fluctuations, while GWO enhances power extraction under severe shading conditions. On the grid side, model predictive control (MPC) optimizes single-phase inverter operation, ensuring stable grid integration and efficient power transfer for residential and microgrid-based electric vehicle (EV) charging. This approach improves dynamic tracking efficiency by over 9% and reduces MPPT tracking time by up to 99.98% compared to conventional methods. Additionally, MPC lowers total harmonic distortion (THD) from 2.56% to 1.56%, enhancing power quality and response time. Implemented on the Texas Instruments TMS320F28379D DSP, the system ensures fast and stable power tracking, outperforming traditional control methods. Both simulations and real-world experiments validate the proposed system, demonstrating significant advancements in PV-based EV charging performance. This study focuses on developing a Hybrid ANN–GWO MPPT combined with MPC-based inverter control to enhance PV-powered EV charging under PSC, aiming to improve tracking efficiency, reduce THD, and implement a real-time DSP-based experimental setup.

KEYWORDS: Hybrid artificial neural network–Grey wolf optimizer (ANN–GWO), model predictive controller, partial shading condition, photovoltaic (PV).

I. INTRODUCTION

The increasing reliance on fossil fuels has significantly exacerbated environmental challenges, including air pollution and global warming, necessitating the adoption of renewable energy solutions, particularly photovoltaic (PV) systems. 1 However, the efficiency of PV systems is highly dependent on environmental factors such as sunlight intensity and temperature variations, 2 leading to performance issues under partial shading conditions (PSCs). To address these limitations, advanced maximum power point tracking (MPPT) techniques have been developed, incorporating artificial intelligence.

In this context, hybrid MPPT methods integrating artificial neural networks (ANNs) with bio-inspired optimization techniques, such as the Grey wolf optimizer (GWO), have demonstrated significant improvements in tracking speed and accuracy. 4 These methods have been further refined to address non-uniform solar irradiation conditions by eliminating conventional weighting parameters and enhancing global convergence. 5 Recent studies highlight the effectiveness of machine learning-driven MPPT algorithms in mitigating power losses under PSC, 6 reinforcing the need for intelligent energy management solutions. Additionally, hybrid approaches integrating heuristic algorithms have shown promising results in overcoming the limitations of traditional MPPT methods. 7 Simultaneously, model predictive control (MPC) has emerged as a robust approach for optimizing inverter switching in grid-connected PV systems, effectively reducing total harmonic distortion (THD) and improving dynamic response. 8 The integration of MPC with hybrid ANN–GWO MPPT strategies has been proposed as a promising solution for next-generation PV-based electric vehicle (EV) charging infrastructures. 9 Recent advancements in hybrid control strategies for power converters further validate the effectiveness of this approach in ensuring stable and efficient power transfer, 10 making it a compelling choice for real-world deployment. Furthermore, recent studies emphasize the importance of adaptive control strategies in enhancing the efficiency of power converters, ensuring reliability in renewable energy applications.

11 Moreover, recent research has explored robust control strategies for wind energy systems, particularly those employing doubly-fed induction generators (DFIGs), highlighting the role of intelligent control methods in optimizing power conversion efficiency. 12 These advanced control strategies, including adaptive backstepping and intelligent direct power control, have demonstrated improved performance in handling real-world wind profiles. 13 Recent studies highlight the effectiveness of machine learning-driven MPPT algorithms in mitigating power losses under PSC, 14 reinforcing the need for intelligent energy management solutions. Simultaneously, MPC has emerged as a robust approach for optimizing inverter switching in grid-connected PV systems, effectively reducing THD and improving dynamic response. 15 The integration of MPC with hybrid ANN-GWO MPPT strategies has been proposed as a promising solution for next-generation PV-based EV charging infrastructures. 16 Recent advancements in hybrid control strategies for power converters further validate the effectiveness of this approach in ensuring stable and efficient power transfer, 17 making it a compelling choice for real-world deployment.

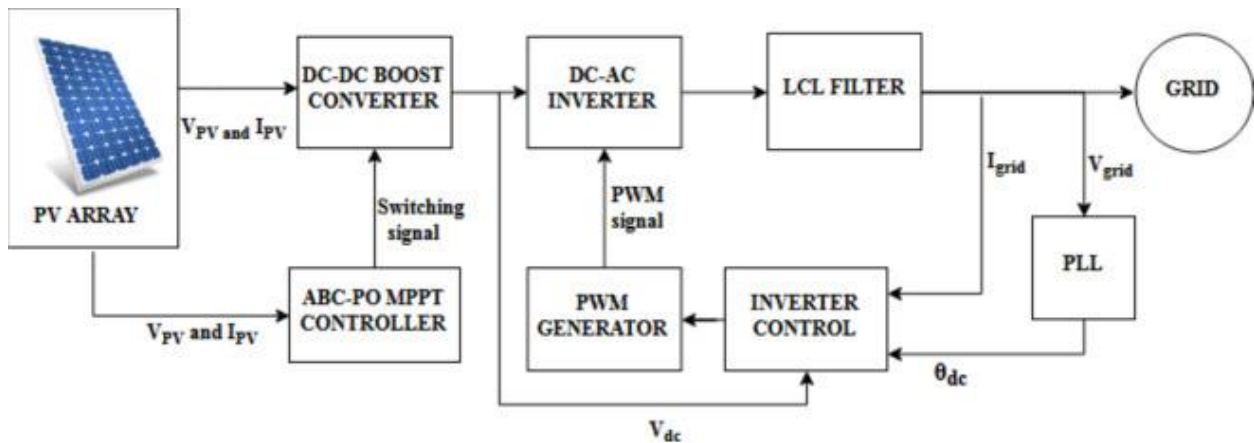


Fig 1: PV system operating under Partially Shaded Conditions with ABC-PO as MPPT

In this study, the PV system is integrated with an EV charger that operates on alternating voltage. The system functions as a small microgrid, consisting of a PV system, a boost converter, an inverter, and an EV charger. A significant barrier to EV adoption is the limited availability of charging infrastructure, which includes high-capacity batteries and robust charging facilities. This system supports both vehicle-to-vehicle (V2V) and vehicle-to-grid (V2G) 18 communication and is capable of managing reactive power. 19 The vehicle-to-home (V2H) mode is designed to optimize the utilization of renewable energy sources, such as PV systems installed in smart homes. Additionally, the smart home model presented in this study includes motor loads. The proposed system employs MPC to convert the output power extracted from the PV system using the ANN-GWO hybrid MPPT algorithm into alternating voltage for efficient EV battery charging. In contrast, this study introduces a novel hybrid ANN-GWO MPPT algorithm, improving the system's adaptability and tracking speed that has been attended 0.02 seconds and extract the maximum power from PV system under PSC. Additionally, by integrating this optimized MPPT with MPC for inverter switching, this work significantly reduces THD from 2.56% to 1.56%, surpassing traditional control strategies. Unlike conventional research that remains simulation-based, this work implements the proposed method on the Texas Instruments TMS320F28379D DSP, validating its real-world feasibility. This study aims to bridge the gap by proposing a hybrid ANN-GWO MPPT algorithm combined with MPC to optimize EV charger performance under PSC. The system is implemented on the Texas Instruments TMS320F28379D DSP, and its effectiveness is validated through MATLAB Simulink simulations and real-world experiments.

II. RELATED WORK

The main contributions of this study include the development of a hybrid ANN-GWO MPPT algorithm that overcomes the conventional limitations of GWO, PSO, ACO, and ABC-based MPPT methods. The ANN plays a crucial role in minimizing response time to 0.02 seconds under changing weather conditions, ensuring faster and more accurate power tracking. The integration of ANN-GWO MPPT with MPC-based inverter control enhances both power tracking and inverter efficiency. Additionally, the proposed approach significantly reduces THD from 2.56% to 1.56%,

outperforming existing PI and fuzzy logic controllers. To validate the effectiveness of the proposed method, real-time implementation on a DSP platform is conducted through experimental testing and simulation.

The adoption of renewable energy systems for generating electrical power is experiencing exponential growth, particularly in the case of PV systems [1,2]. In a central inverter grid-connected PV system, number of PV modules are connected in series to match the requirement of inverter and feed power to the grid. The PV module's series string connection requires to generate same amount of current. Since, the output power of a PV module is significantly influenced by its operating conditions, such as solar irradiance and temperature, and is mainly proportional to the solar irradiance [3]. Among the various parts of the PV system, the PV array is the main part responsible for optimizing the power output. PV module mismatching is the major issue affecting the performance of the PV array [4]. Mismatching occurs when interconnected PV modules have different electrical characteristics or operate at different conditions. Among the various causes of mismatching partial shading is the main reason. Partial shading in PV arrays, caused by elements like leaves and shadows, variation in tilt angle induces a critical scenario, creating module mismatch and compelling the entire array to produce power close to the lowest-performing modules. Additionally, prolonged shading leads to the formation of hotspots, generating heat among shaded cells, resulting in cell breakdown and severe damage to the module [5,6].

Typically, PV modules are comprised of one to four groups of PV cells linked in series, referred to as sub-strings or submodules, frequently integrating bypass diodes to alleviate shading effects. Nevertheless, the dynamic activation and deactivation of these diodes in response to shifting shading conditions can result in suboptimal energy generation, introducing multiple peaks in the power curve alongside a single global maximum power point (GMPP) [7,8]. To address this, advanced maximum power point tracking (MPPT) techniques are suggested in the literature to precisely track the GMPP during partial shading conditions [9]. The interconnection and reconfiguration of PV arrays represent widely preferred techniques employed by numerous researchers to mitigate mismatch losses resulting from complex partial shading. Among various interconnection techniques, TCT (Total Cross-Tied) stands out as the most preferred and widely utilized in PV arrays, demonstrating superior performance in the presence of all types of partial shading when compared to SP (Series-Parallel), BL (bridge linked), and HC (honeycomb) configurations [10,11]. The activation of the bypass diode under a partially shaded PV array hinders the extraction of maximum output despite MPPT techniques, leading to increased system cost, and complexity. Recently power electronics-based solutions with distributed MPPT (DMPPT) have been a growing trend to enhance PV system performance under mismatch conditions. In DMPPT DC-DC converter or microinverter is connected to every PV module or submodule within an array to operate them at their respective maximum power points (MPP) [12]. Implementing DMPPT can be more complex, and costly compared to centralized MPPT solutions, as it involves additional hardware. Also, under uniform irradiance, the continuous Full power processing by DMPPT converters can lead to increased power loss. In the Partial Power Processing (PPP) approach, dedicated converters connected across each module are tasked with processing only the mismatch power between PV modules in a series string, specifically under partial shading conditions. This targeted operation allows for enhanced power output using lower-rated converters with higher efficiency, as highlighted. Various PPP architectures, including PV to PV, PV to bus, and PV to isolated port (IP) significantly improve power output, and eliminate multiple peaks in output characteristics, thereby reducing MPPT loss [[13], [14], [15]]. Furthermore, conventional MPPT techniques can still be applied to track the Maximum Power Point (MPP). However, it's worth noting that these techniques are not without drawbacks, as they may incur increased hardware costs and pose challenges in terms of control complexity. To reduce the control complexity most of the mismatch mitigation techniques are applied at the module level.

To further enhance the PV system performance under partial shading conditions, a submodule level most efficient TCT-TCT PV array interconnection along with the PPP technique is proposed. This could involve more granular control and optimization at the level of individual submodules within a PV array. The proposed combination requires minimum electronic hardware, easy-to-control, modular, and highly efficient PV system architecture to mitigate mismatch losses. The proposed PV system architecture is tested under different mismatch conditions and performance is analysed.

The structure of the paper is as follows: Section II conventional residential system architecture and performance under mismatch conditions is discussed, proposed modified architecture of conventional residential PV system performance under same mismatch conditions is discussed in section III, Section IV presents performance analysis and comparison, and Section V provides the conclusions.

III. METHODS

ilt angle has a major impact on solar radiation incident on the surface of PV module or array. The optimal fixed tilt angle of the PV array maintains the uniform solar irradiance over the surface of all the PV modules, and it also operates all PV cells at the same temperature. However, if there is a variation in the tilt angle of PV modules in the array results in a mismatch condition similar to that occurred during partial shadings. The effect of the variation of tilt angle on the solar irradiance received on the surface of one PV module. It is noticed that at the optimum tilt angle, maximum irradiance is received by the module, and for other values it is decreased. In both mismatch conditions, solar irradiance received by the PV module in the array is nonuniform.

Two highly efficient mismatch mitigation techniques such as TCT-TCT PV array interconnection and differential power processing (DPP) are applied as proposed in. The proposed array interconnection enhances the power output by equalizing the irradiation levels and DPP converter prevents the activation of the shaded submodule bypass diode providing the path for mismatch currents. This configuration reduce the hardware required compared with series string presented in. The restricted power generation under shading conditions can be further enhanced by using DPP converters. In proposed submodule level DPP architecture PV module is assumed to have two submodules (SM) forms one group and such two submodule groups (two PV modules) forms another group. Bidirectional buck boost converter (BBBC) is used to compensate the mismatching between two submodules within a group. The resonant switched converter (ReSC) is used to compensate the mismatch within a group of two PV modules.

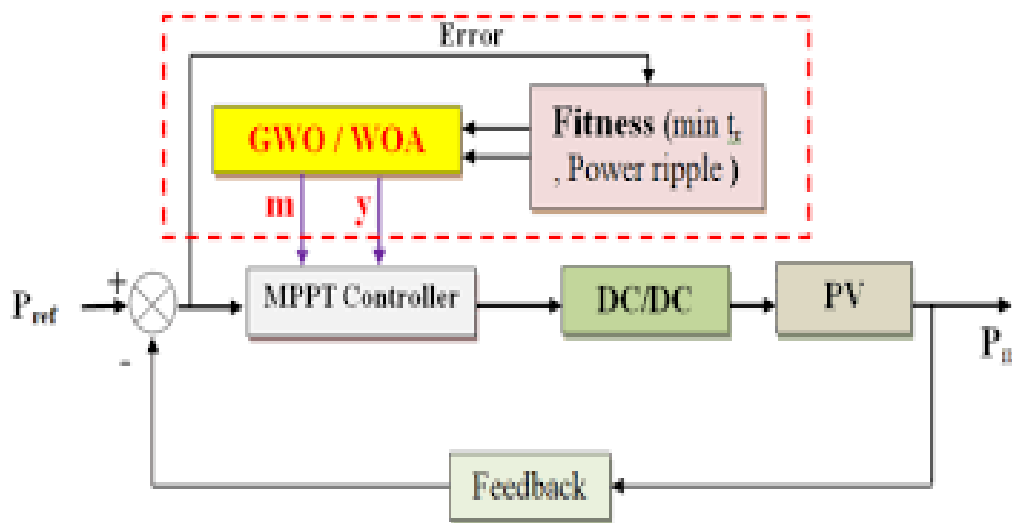


Fig 2: GWO and WOA variable step MPPT algorithms

The power conversion efficiency of existed PV configuration and modified configurations under uniform irradiance condition (U1-U4) remain constant irrespective of irradiance level and is equal to 95 % and 99 % respectively. For operation under nonuniform operating conditions the power conversion efficiency showed dependency on mismatch levels between PV elements of existed PV system configuration. It gets reduced from 95 % to 72 % with increase in mismatch between PV elements of array. The modified PV configurations power conversion efficiency under nonuniform irradiance operation remain constant (99 %) irrespective of mismatch levels.

The system is located in India Maharashtra Aurangabad having latitude and longitude coordinates of 19.880 N and 75.350 E. The system is installed with an optimal fixed tilt angle of 17.3° facing south. To study the performance of system mismatch conditions created by changing the irradiance level received by the PV modules in the array. In this study only mismatch due to nonuniform irradiance is considered for performance analysis since the other parameters such as temperature, humidity, wind speed, and manufacturing dissimilarities creates small mismatches hence not considered. The solar irradiance over the PV modules in the string is artificially changed by covering with different transparent sheets (plastic, cloth, glass, and paper) or by varying the tilt angle. First the actual solar irradiance over a

PV module without covering is measured and then the modules are covered with these sheets and irradiance over the module is measured.

IV. RESULT ANALYSIS

The system is applied with three different levels of solar irradiance. The corresponding levels of maximum power obtained, the Pulse Width Modulation (PWM) signal applied to the converter, and output voltage variations are noted for these three levels of partial shading. In case 1, two PV panels are fully illuminated with 1000 W/m², but the third panel is shaded by applying 800 W/m² solar irradiance. The FA algorithm optimizes the output by using the population of fireflies, random value, and multiple iterations. Finally it reaches to 60.03W output power with 98.12% tracking efficiency as shown in Figure 7. The required PWM variations and the output voltage are shown in Figure 8 and Figure 9 respectively. In case 2, only one PV panel is fully illuminated with 1000 W/m², and remaining two panels are shaded by applying 900 W/m² and 800 W/m² solar irradiance. The FA algorithm optimizes the output for this partial shading condition. Finally it reaches to 58.23W output power with 97.05% tracking efficiency.

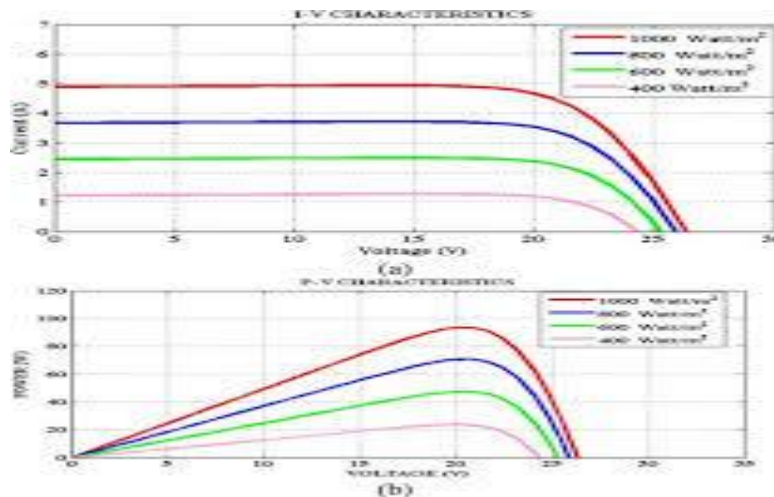


Fig 3: Optimization with Self-Tuned Fuzzy Logic MPPT Controller

The work focuses on the experimental analysis of the impact of partial shading on the performance of PV systems and the proposed method using Firefly Algorithm for GMPPT. A deep investigation is done with the experimentation by using PV emulator. A reduction of 37% in MPP, a reduction of 38% in fill factor, and a reduction of 60% in efficiency is observed due to partial shading. The proposed novel metaheuristic optimization approach using the Firefly Algorithm to track the global MPP is able to track the GMPP accurately. The algorithm efficiently explores the search space by focusing on the global peak and local peaks. The algorithm is tested under different levels of partial shading. The proposed method is able to achieve 98.12% tracking efficiency within 1ms tracking time. The developed MPPT outperforms conventional MPPT methods in terms of efficiency, convergence speed, and oscillations around MPP. The FA algorithm can also be scaled up for the larger and complex PV systems.

While the FA is effective in handling non-linear and multimodal problems in MPPT, it has several limitations. It has higher computational complexity as compared to few other optimization algorithms. The performance of FA depends heavily on parameter tuning. The higher complexity of FA may not be suitable with embedded systems having limited memory and computational power, especially for low-cost PV systems. To address these problems, the hybrid methods can be developed by incorporating FA with other algorithms such as PSO or GWO. Adaptive techniques such as Fuzzy logic or neural network can be used with the FA technique for adaptive tuning of parameters. Parallel computing technique can be used to reduce the computational complexity of FA method. Such future research directions ensure that the FA can be considered as a suitable choice for real time MPPT.

V. CONCLUSION

In conclusion, this study presents a comprehensive approach to improving the efficiency of solar-powered EV charging systems, particularly under PSCs. By integrating a hybrid ANN–GWO-based MPPT algorithm with MPC, the system achieves significant enhancements in voltage quality, response time, and overall performance. The proposed hybrid ANN–GWO algorithm effectively tracks the GMPP, reducing tracking time by up to 99.98% and improving dynamic tracking efficiency by over 9% compared to traditional methods. Additionally, the MPC approach minimizes THD to as low as 1.56%, demonstrating superior performance over conventional MPC strategies. Both simulation and real-world experiments confirm the robustness and effectiveness of the proposed system, representing a significant advancement in solar-powered EV charging technology. The hybrid ANN–GWO MPPT with MPC control offers promising applications in grid-connected EV charging stations, smart microgrids, and off-grid PV systems. Future work will focus on scaling the system for large-scale PV installations and incorporating adaptive thermal management to enhance performance stability under varying temperature conditions.

REFERENCES

- 1.Ritchie H, Roser M. Energy production and consumption. Our World in Data, <https://ourworldindata.org/energy-production-consumption> (2020).
- 2.Al-Amoudi A, Zhang L. Optimal control of a grid-connected PV system for maximum power point tracking. *IEEE Proc Electr Power Appl* 2001; 148: 567–572. [Google Scholar]
- 3.Mekhilef S, Saidur R, Safari A. Comparative study of maximum power point tracking techniques for photovoltaic system. *Renewable Sustainable Energy Rev* 2012; 16: 2865–2879. [Google Scholar]
- 4.Liang J, Ye C, Wang Z. Hybrid MPPT method based on artificial neural network and grey wolf optimizer. *IEEE Trans Energy Convers* 2021; 36: 187–198. [Google Scholar]
- 5.Rahmani R, Shahbakhti M, Askarzadeh S. A novel ANN–GWO-based MPPT controller for PV systems under non-uniform solar irradiation. *Sol Energy* 2020; 203: 122–135. [Google Scholar]
- 6.Nguyen TH, Nguyen HT, Pham MT. Machine learning-driven MPPT algorithms for PV systems under partial shading conditions. *Energy Rep* 2021; 7: 1248–1256. [Google Scholar]
- 7.Cortés P, Kazmierkowski MP, Kennel R, et al. Predictive control in power electronics and drives. *IEEE Trans Ind Electron* 2008; 55: 4312–4324. [Google Scholar]
- 8.Mishra AK, Rout PK, Ray PK. A hybrid ANN–GWO–MPC approach for optimal energy management in PV-based EV charging infrastructure. *IEEE Trans Smart Grid* 2021; 12: 2341–2352. [Google Scholar]
- 9.Blaabjerg F, Yang Y, Yang Det al. et al. Hybrid control strategies for power converters: advancements and applications. *IEEE J Emerg Sel Top Power Electron* 2020; 8: 1435–1452. [Google Scholar]
- 10.Bansal RK, Laghari MA, Subramaniam PSBR. Hybrid metaheuristic optimization techniques for MPPT under partial shading. *Control Comput* 2024; 2024: 101960. [Google Scholar]
- 11.Khan MS, Qureshi SA. Adaptive power control in renewable energy systems using hybrid optimization techniques. *J Comput Sci* 2024; 8: 158. [Google Scholar]
- 12.Yessef M, Bossoufi B, Taoussi M, et al. Robust control of a wind conversion system based on a doubly fed induction generator: a comparison between adaptive backstepping and integral sliding mode controllers. In: *Lecture notes in networks and systems*, Vol. 454. Cham: Springer, 2022. DOI: 10.1007/978-3-031-01942-5_72. [DOI] [Google Scholar]
- 13.Yessef M, Bossoufi B, Taoussi M, et al. Intelligent direct power control based on the neural super-twisting sliding mode controller of a DFIG. *Lecture notes in networks and systems*, Vol. 669. Cham: Springer, 2023. DOI: 10.1007/978-3-031-29860-8_73. [DOI] [Google Scholar]
- 14.Rahman MM, Islam MS. PSO and ANN based hybrid MPPT algorithm for photovoltaic array under partial shading condition. *Eng Int* 2020; 8: 9–24. [Google Scholar]
- 15.Luo H, Wen H, Li X, et al. Synchronous buck converter based low-cost and high-efficiency sub-module DMPPT PV system under partial shading conditions. *Energy Convers Manag* 2016; 126: 473–487. [Google Scholar]



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details