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OPINION
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Current Status, Challenges, and Trends of Maximum Power Point Tracking for PV Systems

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INTRODUCTION

Owing to environment deterioration (Xi et al., 2016), fossil energy depletion, and air contamination, the reform of the energy structure and the development (Yang et al., 2020a; Sun and Yang 2020) of sustainable ecological (Kalyan and Rao 2021) are imminent in recent years, in which various renewable energy technologies (Yang et al., 2020b; Noman et al., 2021) as efficient alternative energy, for example, wind, solar (Iqbal et al., 2021), and hydropower, have attracted extensive focus. Particularly, as a decisive form of solar energy exploitation and utilization, photovoltaic (PV) systems (Bakeer et al., 2021) possess enormous social and economic benefits. Thus, the applications of maximum power point tracking (MPPT) technologies (Yang et al., 2020c) are extremely crucial for PV systems owing to multiple local maximum power points (LMPPs) and a global maximum power point (GMPP) under partial shading conditions (PSCs) (Zhao et al., 2021). However, due to the high nonlinearity of power and voltage (P-V) characteristics resulting in power loss and hot spot effect under PSCs, the exploration of effective MPPT technology is hindered. For the purpose of obtaining MPPT technologies with better tracking accuracy and efficiency in PV systems, a large number of scholars have carried out extensive discussion and research, while the practical relevance of MPPT techniques faces several challenges. The first is that most of the existing research focuses on simulation, rather than the actual experiment. In addition, the subsequent research not only pursues the tracking accuracy but also explores the appropriate MPPT technology (Zhao et al., 2021) after fully considering the balance between the tracker cost and additional power income. This article clarifies the aforementioned matters and raises certain perceptive on multiple PV MPPT technologies.

UNIFORM SOLAR IRRADIATION

When PV systems work normally, the internal resistance of the PV cell will change with a change in solar irradiance and temperature. Based on the same solar irradiance and temperature, PV cells output various voltages, while only maximum power can be achieved at a certain voltage, which is called the maximum power point (MPP) (Liu et al., 2016). It is obvious that the essence of MPPT is self-optimized, which is realized by adjusting the output voltage of the PV cells (i.e., matching the P-V operating point with a relevant power converter). Especially, the PV systems can obtain a single GMPP under uniform irradiation, which is called a single peak characteristic (Ishaque and Salam 2013). The traditional MPPT technologies under uniform irradiation are extremely critical to the single-peak power extraction of PV systems. In addition, multitudinous MPPT technologies of PV systems have been advanced composed of two categories (Yang et al., 2019a; Yang et al., 2019b), that is, the conventional technology, namely, the perturb and observe (P&O), incremental conductance (INC), and the hill climbing (HC), and the improved conventional technology.

The conventional technologies obtained under uniform irradiation have excellent power enhancement performance of PV systems. In one cycle, P&O (Ahmed and Salam 2015; Alik and Jusoh 2018) adds a preset voltage increment (ΔV), causing disturbance to the PV cell voltage, while the output power before and after the disturbances is calculated and compared to determine the direction of the next disturbance. P&O is extensively adopted for engineering practicability, while the more complicated oscillation delay of P&O is an obstacle, leading to increased power loss and decreased stability. In addition, INC is a classical algorithm to fulfill the MPPT (Zakzouk et al., 2016; Harrag and Messalti 2019), whose principle is to change the PV control signal by comparing the derivative of the output power to the output voltage of the PV cell. There is no doubt that the voltage oscillation range of INC is smaller than that of P&O, but the hardware requirements of INC are higher according to the difficulty of calculating. Furthermore, HC applies for duty cycle disturbance (Lasheen and Abdel-Salam 2018), instead of voltage increment disturbance, which is inconsistent with P&O. Due to the limitation of step size and long calculation time (Lasheen and Abdel-Salam 2018), the aforementioned technologies are unobtainable to track the real-time GMPP.

For tackling these defects, the quantities of scholars have concentrated on satisfactory variant technologies achieved through different optimizations. Ahmed and Salam (2015) illustrated an adaptive variable step size strategy, which can intelligently convert the size of voltage disturbance by the adaptive mechanism to minimize the steady-state oscillation. In Ali and Mohamed (2022), a robust modified P&O based on an open-circuit voltage estimation is designed, upon which the GMPP is quickly tracked by subdividing the working area of the PV cell's *P-V* curve. In Belkaid et al. (2016), the improved INC technology avoids divergences of MPP of the PV system by fine-tuning the duty cycle of the DC/DC converter, while it is the slow time response at the startup compared to other methods.

Both conventional technology and variant conventional technology have an inherent defect, that is, MPPT can only be performed on the PV system where only one MPP exists in the *P-V* curve under uniform irradiance (Belhachat and Larbes 2018; Yang et al., 2020d). This enormous defect leads to greater restrictions on its application in more practical engineering fields (Li et al., 2018). Therefore, researchers should focus on more advanced multi-peak MPPT strategies in the future, where all PV cells in the same module and all modules in the same string are exposed to different solar irradiation and temperatures.

PARTIAL SHADING CONDITION

In fact, when PV systems are affected by PSCs (Sangwongwanich and Blaabjerg 2019), their *P-V* characteristics will become nonlinear. Concretely, since the large-scale PV system will inevitably be obscured by passing clouds, building shadows, bird droppings, dust, etc., the irradiance and temperature of these parts are different from those of the other parts, which will engender multiple LMPPs and only one GMPP on the *P-V* curve. Distinctively, **Figure 1** depicts the *P-V* characteristic curves of PV systems under uniform solar irradiation and PSCs, upon which the differences between the GMPP and LMPPs can be reflected intuitively. Furthermore, a series of problems such as output power losses, hot spot effects, and security and dependability issues also appear in the PV systems under PSCs. At present, the technological progress related to MPP subject has grown tremendously (Ahmad et al., 2019), upon which meta-heuristic algorithms (MhAs), artificial neural network (ANN), deep learning technologies, and so forth are explored and applied in PV systems.

The remarkable advantage of MhAs is that their efficiency is higher than that of blind search methods, which obtain an optimal solution in a short time due to no complex gradient information, uncomplicated operation mechanism, and easy modification. The classical meta-heuristic algorithms such as genetic algorithm (GA) (Hua and Zhan 2021), particle swarm optimization (PSO) (Alshareef et al., 2019), gray wolf optimization (GWO) (Pai and Tseng 2019), moth flame optimization (MFO) (Shi et al., 2019), and ant colony optimization (ACO) (Sundareswaran et al., 2020) have been applied for GMPP tracking to opportunely escape LMPPs. Nowadays, in order to balance local exploitation and global exploration, significant MhAs with promising experimental performance are studied, while the aforementioned algorithms are usually regarded as competition algorithm to compare the tracking ability of the GMPP. For example, the duty cycle of the converter is controlled based on the bat algorithm (BA) (Seyedmahmoudian et al., 2018), so that MPPT can be performed faster, more efficiently, and more sustainably under distinct PSCs. In Fares et al. (2021), the problem of excessive randomness in the initial stage is effectively alleviated by the improved squirrel search algorithm (ISSA), so that high disturbance and power loss are fully reduced.

Although the pure single meta-algorithms (MhAs) have proposed a decent performance of getting rid of LMPPs, the intrinsic imperfections are inescapable due to premature convergence and many computing iterations. It is worth affirming that a variety of optimization strategies are mixed to avoid the defects and intensify the superiorities of pure single MhAs. Among these, the improvements of several hybrid MhAs are purposed, for example, differential evolutionary algorithm and PSO (DEPSO) (Seyedmahmoudian et al., 2015), hybrid Jaya algorithm and differential evolution (Jaya-DE) (Kumar et al., 2017), and salp swarm algorithm with GWO (SSA-GWO) (Wan et al., 2019), and so on. For example, using the hybrid conventional technologies and meta-heuristic algorithms, Senniappan and Umapathy (2021) devised an exceptional hybridized human psychology optimization-P&O (HPO-PO) to achieve the GMPP by adjusting the optimal duty cycle of the boost converter. In addition, there are other optimization algorithms of this type, such as artificial bee colony-integrated P&O (ABC-PO) (Pilakkat and Kanthalakshmi 2020), PSO-combined P&O (PSO-PO) (Sundareswaran et al., 2015), and hybrid GWO–P&O (GWO-PO) (Mohanty et al., 2017). The aforementioned hybrid algorithms can enhance the tracking

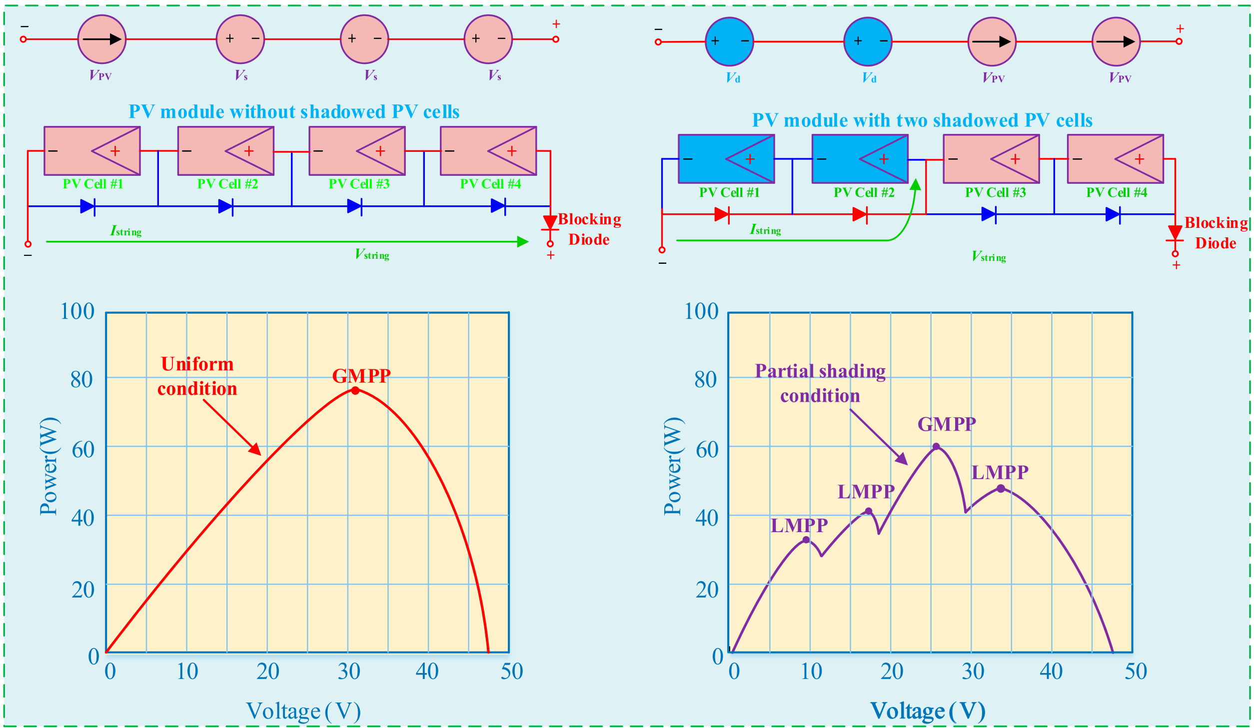

FIGURE 1 | *P-V* characteristic curves of PV systems.

speed, tracking accuracy, and stability to a certain extent, but they are still unqualified when dealing with more extreme datasets and higher accuracy requirements.

It is worth mentioning that abundant studies have deliberated on the application of artificial intelligence (AI) methods in MPPT of PV systems. The ANN with prediction is conceived as the estimator of MPPT after comprehensive training, such as the GA optimized ANN (GA-ANN) (Bollipo et al., 2021), hybrid shuffled frog leaping and pattern search (HSFL-PS) algorithm-based neural network (Jiang et al., 2021), and Bayesian network (BN) (Jiang et al., 2021). In addition, fuzzy logic control (FLC) (Hassan et al., 2020) is a brilliant method since it tracks the GMPP without considering the possibility of losing source information obtained under different PSCs. Because of its brilliant benefits, a number of improved and hybrid variants of FLC are proposed; for example, Al-Gizi et al. (2018) revealed that hybrid P&O and FLC (PO-FLC) shows better tracking GMPP results than the pure traditional FLC. In addition, the other AI methods, including sliding mode control (SMC), Fibonacci series, memetic reinforcement learning (MRL), and transfer reinforcement learning (TRL) are developed to efficiently enhance the optimal quality with satisfactory tracking speed and stability (Yang et al., 2020d). AI methods can accomplish low oscillation rate and high tracking speed at GMPP, while it is worth noting that these methods are applied in a variety of system simulation experiments, rather than practical engineering.

Ultimately, each of the aforementioned technologies has its own relative merits in terms of component cost, implementation complexity, parameter optimization, tracking accuracy, tracking speed, etc. Thus, engineering application factors such as cost, complexity of hardware implementation, and measurement error should be comprehensively considered, while the current research lacks more rationale and equitable evaluation criteria to make an explicit and integrated comparison of various MPPT methods. Furthermore, research is deficient on whether the proposed methods perform notably for PV plants of different levels and scales, which is considered as an indispensable matter to be solved in the application of PV system MPPT. In addition, these kinds of studies do not point out the concrete impact of the actual data noise (extreme datasets) on MPPT in PV systems, so that the feasibility and practicability in industrial production are reduced. For this purpose, anti-interference and robustness experiments of numerous methods should be realized based on various types of general data noise to ensure the efficiency of MPPT in the specific application environment.

CONCLUSION

Improving the power generation efficiency of PV systems has become the main driving force to promote the development of solar energy, while the research and development of multiple MPPT technologies can be further strengthened under the dynamic PSCs. MPPT technologies based on comprehensive consideration indexes such as tracking speed, output power quality, vibration, and implementation complexity are still insufficient, upon which main conclusions are contained as follows:

- More practical experiments should be carried out to further test the performance of various MPPT technologies since most technologies are evaluated only through simulation tests.
- Comprehensive evaluation of the cost, accuracy, complexity, and other indicators of MPPT technologies instead of tracking speed and power output should be carried out, so that the proposed technologies have satisfied operability and practicability.
- Whether the proposed technologies have satisfactory compatibility in all-scale PV power stations is also under discussion after considering the balance between the tracker cost and the extra power revenue.
- The impact of objectively existing data noise on the MPPT is worth exploring by selecting several reasonable types of data noise to simulate, while various positive methods are probed to eliminate their disturbance.

AUTHOR CONTRIBUTIONS

CZ: writing the original draft and editing. BY: conceptualization. PC: visualization and contributed to the discussion of the topic. QL: investigation and validation. JD: writing—reviewing and editing. ST: revised the draft according to others' comments.

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REFERENCES

Ahmad, R., Murtaza, A. F., and Sher, H. A. (2019). Power Tracking Techniques for Efficient Operation of Photovoltaic Array in Solar Applications - A Review. *Renew. Sustain. Energ. Rev.* 101, 82–102. doi:10.1016/j.rser.2018.10.015

Ahmed, J., and Salam, Z. (2015). An Improved Perturb and Observe (P&O) Maximum Power point Tracking (MPPT) Algorithm for Higher Efficiency. *Appl. Energ.* 150, 97–108. doi:10.1016/j.apenergy.2015.04.006

Al-Gizi, A., Craciunescu, A., Fadel, M. A., and Louzazni, M. (2018). A New Hybrid Algorithm for Photovoltaic Maximum Power point Tracking under Partial Shading Conditions. *Revue Roumaine Des Sci. Tech.* 63 (1), 52–57.

Ali, A. I. M., and Mohamed, H. R. A. (2022). Improved P&O MPPT Algorithm with Efficient Open-Circuit Voltage Estimation for Two-Stage Grid-Integrated PV System under Realistic Solar Radiation. *Int. J. Electr. Power Energ. Syst.* 137, 107805. doi:10.1016/j.ijepes.2021.107805

Alik, R., and Jusoh, A. (2018). An Enhanced P&O Checking Algorithm MPPT for High Tracking Efficiency of Partially Shaded PV Module. *Solar Energy* 163, 570–580. doi:10.1016/j.solener.2017.12.050

Alshareef, M., Lin, Z., Ma, M., and Cao, W. (2019). Accelerated Particle Swarm Optimization for Photovoltaic Maximum Power point Tracking under Partial Shading Conditions. *Energies* 12 (4), 623. doi:10.3390/en12040623

Bakeer, A., Salama, H. S., and Vokony, I. (2021). Integration of PV System with SMES Based on Model Predictive Control for Utility Grid Reliability Improvement. *Prot. Control. Mod. Power Syst.* 6, 14. doi:10.1186/s41601-021-00191-1

Belhachat, F., and Larbes, C. (2018). A Review of Global Maximum Power point Tracking Techniques of Photovoltaic System under Partial Shading Conditions. *Renew. Sustain. Energ. Rev.* 92, 513–553. doi:10.1016/j.rser.2018.04.094

Belkaid, A., Colak, I., and Isik, O. (2016). Photovoltaic Maximum Power point Tracking under Fast Varying of Solar Radiation. *Appl. Energ.* 179, 523–530. doi:10.1016/j.apenergy.2016.07.034

Bollipo, R. B., Mikkili, S., and Bonthagorla, P. K. (2021). Hybrid, Optimal, Intelligent and Classical PV MPPT Techniques: A Review. *CSEE J. Power Energ. Syst.* 7 (1), 9–33. doi:10.17775/CSEEJPES.2019.02720

Fares, D., Fathi, M., Shams, I., and Mekhilef, S. (2021). A Novel Global MPPT Technique Based on Squirrel Search Algorithm for PV Module under Partial Shading Conditions. *Energ. Convers. Manage.* 230, 113773. doi:10.1016/j.enconman.2020.113773

Harrag, A., and Messalti, S. (2019). IC-based Variable Step Size Neuro-Fuzzy MPPT Improving PV System Performances. *Energ. Proced.* 157, 362–374. doi:10.1016/j.egypro.2018.11.201

Hassan, T.-u., Abbassi, R., Jerbi, H., Mehmood, K., Tahir, M. F., Cheema, K. M., et al. (2020). A Novel Algorithm for MPPT of an Isolated PV System Using Push Pull Converter with Fuzzy Logic Controller. *Energies* 13 (15), 4007. doi:10.3390/en13154007

Hua, C.-C., and Zhan, Y.-J. (2021). A Hybrid Maximum Power point Tracking Method without Oscillations in Steady-State for Photovoltaic Energy Systems. *Energies* 14 (18), 5590. doi:10.3390/en14185590

Iqbal, B., Nasir, A., and Murtaza, A. F. (2021). Stochastic Maximum Power point Tracking of Photovoltaic Energy System under Partial Shading Conditions. *Prot. Control. Mod. Power Syst.* 6, 30. doi:10.1186/s41601-021-00208-9

Ishaque, K., and Salam, Z. (2013). A Review of Maximum Power point Tracking Techniques of PV System for Uniform Insolation and Partial Shading Condition. *Renew. Sustain. Energ. Rev.* 19, 475–488. doi:10.1016/j.rser.2012.11.032

Jiang, M., Ghahremani, M., Dadfar, S., Chi, H., Abdallah, Y. N., and Furukawa, N. (2021). A Novel Combinatorial Hybrid SFL-PS Algorithm Based Neural Network with Perturb and Observe for the MPPT Controller of a Hybrid PV-Storage System. *Control. Eng. Pract.* 114, 104880. doi:10.1016/j.conengprac.2021.104880

Kalyan, C. H. N. S., and Rao, G. S. (2021). Impact of Communication Time Delays on Combined LFC and AVR of a Multi-Area Hybrid System with IPFC-RFBs Coordinated Control Strategy. *Prot. Control. Mod. Power Syst.* 6, 12. doi:10.1186/s41601-021-00185-z

Kumar, N., Hussain, I., Singh, B., and Panigrahi, B. K. (2017). Rapid MPPT for Uniformly and Partial Shaded PV System by Using JayaDe Algorithm in Highly Fluctuating Atmospheric Conditions. *IEEE Trans. Ind. Inf.* 13 (5), 2406–2416. doi:10.1109/tii.2017.2700327

Lasheen, M., and Abdel-Salam, M. (2018). Maximum Power point Tracking Using hill Climbing and ANFIS Techniques for PV Applications: A Review and a Novel Hybrid Approach. *Energ. Convers. Manage.* 171, 1002–1019. doi:10.1016/j.enconman.2018.06.003

Li, G., Jin, Y., Akram, M. W., Chen, X., and Ji, J. (2018). Application of Bio-Inspired Algorithms in Maximum Power point Tracking for PV Systems under Partial Shading Conditions - A Review. *Renew. Sustain. Energ. Rev.* 81, 840–873. doi:10.1016/j.rser.2017.08.034

Liu, L., Meng, X., and Liu, C. (2016). A Review of Maximum Power point Tracking Methods of PV Power System at Uniform and Partial Shading. *Renew. Sustain. Energ. Rev.* 53, 1500–1507. doi:10.1016/j.rser.2015.09.065

Mohanty, S., Subudhi, B., and Ray, P. K. (2017). A Grey Wolf-Assisted Perturb & Observe MPPT Algorithm for a PV System. *IEEE Trans. Energ. Convers.* 32 (1), 340–347. doi:10.1109/tec.2016.2633722

Noman, M., Li, G., Wang, K., and Han, B. (2021). Electrical Control Strategy for an Ocean Energy Conversion System. *Prot. Control. Mod. Power Syst.* 6, 12. doi:10.1186/s41601-021-00186-y

Pai, F.-S., and Tseng, P.-S. (2019). An Efficient GWO MPPT for a PV System Using Impedance Information Acceleration. *Int. J. Electro.* 106 (4), 648–661. doi:10.1080/00207217.2018.1545929

Pilakkat, D., and Kanthalakshmi, S. (2020). Single Phase PV System Operating under Partially Shaded Conditions with ABC-PO as MPPT Algorithm for Grid Connected Applications. *Energ. Rep.* 6, 1910–1921. doi:10.1016/j.egyr.2020.07.019

Sangwongwanich, A., and Blaabjerg, F. (2019). Mitigation of Interharmonics in PV Systems with Maximum Power point Tracking Modification. *IEEE Trans. Power Electron.* 34 (9), 8279–8282. doi:10.1109/tpel.2019.2902880

Senniappan, G., and Umapathy, P. (2021). A Novel Hybrid Human Psychology Optimization-Perturb and Observe MPPT Algorithm in a dsPIC Microcontroller for Grid Connected PV Power System. *Ifs* 41 (2), 3011–3030. Journal of Intelligent & Fuzzy Systems. doi:10.3233/jifs-210114

Seyedmahmoudian, M., Kok Soon, T., Jamei, E., Thirunavukkarasu, G., Horan, B., Mekhilef, S., et al. (2018). Maximum Power point Tracking for Photovoltaic Systems under Partial Shading Conditions Using Bat Algorithm. *Sustainability* 10 (5), 1347. doi:10.3390/su10051347

Seyedmahmoudian, M., Rahmani, R., Mekhilef, S., Maung Than Oo, A., Stojcevski, A., Soon, T. K., et al. (2015). Simulation and Hardware Implementation of New Maximum Power point Tracking Technique for Partially Shaded PV System Using Hybrid DEPSO Method. *IEEE Trans. Sustain. Energ.* 6 (3), 850–862. doi:10.1109/tste.2015.2413359

Shi, J. Y., Zhang, D. Y., Xue, F., Li, Y. J., Qiao, W., Yang, W. J., et al. (2019). Moth-flame Optimization-Based Maximum Power point Tracking for Photovoltaic Systems under Partial Shading Conditions. *J. Power Electro.* 19 (5), 1248–1258. doi:10.6113/JPE.2019.19.5.1248

Sun, L. M., and Yang, B. (2020). Nonlinear Robust Fractional-Order Control of Battery/SMES Hybrid Energy Storage Systems. *Power Syst. Prot. Control.* 48 (22), 76–83. doi:10.19783/j.cnki.pspc.191598

Sundareswaran, K., Satheesh, K. G., Simon, S. P., and Nayak, P. (2020). MPPT in PV Systems Using Ant colony Optimization with Dwindling Population. *IET Renew. Power Generation* 14 (7), 1105–1112. doi:10.1049/iet-rpg.2019.0875

Sundareswaran, K., Vignesh kumar, V., and Palani, S. (2015). Application of a Combined Particle Swarm Optimization and Perturb and Observe Method for MPPT in PV Systems under Partial Shading Conditions. *Renew. Energ.* 75, 308–317. doi:10.1016/j.renene.2014.09.044

Wan, Y., Mao, M., Zhou, L., Zhang, Q., Xi, X., and Zheng, C. (2019). A Novel Nature-Inspired Maximum Power point Tracking (MPPT) Controller Based on SSA-GWO Algorithm for Partially Shaded Photovoltaic Systems. *Electronics* 8, 680. doi:10.3390/electronics8060680

Xi, L., Yu, T., Yang, B., Zhang, X., and Qiu, X. (2016). A Wolf Pack Hunting Strategy Based Virtual Tribes Control for Automatic Generation Control of Smart Grid. *Appl. Energ.* 178, 198–211. doi:10.1016/j.apenergy.2016.06.041

Yang, B., Zhong, L., Zhang, X., Shu, H., Yu, T., Li, H., et al. (2019a). Novel Bio-Inspired Memetic Salp Swarm Algorithm and Application to MPPT for PV Systems Considering Partial Shading Condition. *J. Clean. Prod.* 215, 1203–1222. doi:10.1016/j.jclepro.2019.01.150

Yang, B., Yu, T., Zhang, X., Li, H., Shu, H., Sang, Y., et al. (2019b). Dynamic Leader Based Collective Intelligence for Maximum Power point Tracking of PV Systems Affected by Partial Shading Condition. *Energ. Convers. Manage.* 179, 286–303. doi:10.1016/j.enconman.2018.10.074

Yang, B., Zhu, T., Zhang, X., Wang, J., Shu, H., Li, S., et al. (2020). Design and Implementation of Battery/SMES Hybrid Energy Storage Systems Used in Electric Vehicles: A Nonlinear Robust Fractional-Order Control Approach. *Energy* 191, 116510. doi:10.1016/j.energy.2019.116510

Yang, B., Wang, J., Zhang, M., Shu, H., Yu, T., Zhang, X., et al. (2020b). A State-Of-The-Art Survey of Solid Oxide Fuel Cell Parameter Identification: Modelling, Methodology, and Perspectives. *Energ. Convers. Manage.* 213, 112856. doi:10.1016/j.enconman.2020.112856

Yang, B., Zhang, M., Zhang, X., Wang, J., Shu, H., Li, S., et al. (2020). Fast Atom Search Optimization Based MPPT Design of Centralized Thermoelectric Generation System under Heterogeneous Temperature Difference. *J. Clean. Prod.* 248, 119301. doi:10.1016/j.jclepro.2019.119301

Yang, B., Zhu, T., Wang, J., Shu, H., Yu, T., Zhang, X., et al. (2020d). Comprehensive Overview of Maximum Power point Tracking Algorithms of PV Systems under Partial Shading Condition. *J. Clean. Prod.* 268, 121983. doi:10.1016/j.jclepro.2020.121983

Zakzouk, N. E., Elsaharty, M. A., Abdelsalam, A. K., Helal, A. A., and Williams, B. W. (2016). Improved Performance Low-cost Incremental Conductance PV MPPT Technique. *IET Renew. Power Generation* 10 (4), 561–574. doi:10.1049/iet-rpg.2015.0203

Zhao, Y., An, A., Xu, Y., Wang, Q., and Wang, M. (2021). Model Predictive Control of Grid-Connected PV Power Generation System Considering Optimal MPPT Control of PV Modules. *Prot. Control. Mod. Power Syst.* 6, 32. doi:10.1186/s41601-021-00210-1

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