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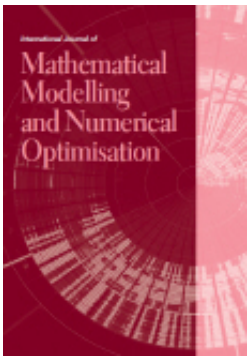

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Retrospection and investigation of ANN-based MPPT technique in comparison with soft computing-based MPPT techniques for PV solar and wind energy generation system

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Retrospection and investigation of ANN-based MPPT technique in comparison with soft computing-based MPPT techniques for PV solar and wind energy generation system

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Abstract: This article discusses the previously available research and summarises the state of knowledge of soft computing artificial neural network (ANN)-based control techniques for renewable energy systems. In recent years, wind and photovoltaic (PV) solar energy systems have been developed as key renewable energy sources. The main issue is to operate these energy sources for maximum power output in abrupt changes in environmental conditions. Besides different types of conventional control techniques, the soft computing-based control system has proved efficient in extracting the highest available output. There are few articles available in the literature on ANN-based control systems in wind energy systems, however, sufficient research has been carried out for the ANN-based maximum power extraction techniques for PV solar. This article highlights the important features such as better controllability and performance of ANN-based control techniques in comparison with the other types of soft computing-based-tactics for PV solar and wind energy systems.

Keywords: traditional algorithm; novel algorithm; hybrid algorithm; artificial neural network; ANN; solar photovoltaic; wind; renewable; maximum power point tracking.

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1 Introduction

The development and inventions in the field of new soft-technique-based control methods are increased rapidly in the last few years and helped in improving the economy by making efficient systems. In the recent past, the use of artificial neural network (ANN)-based control methods has increased in the field of energy generation with the development of renewable energy sources. It provides better and more efficient controllability. Therefore, nowadays, researchers' attention is getting attracted to ANN-based control technology (Grossi and Buscema, 2007; Rahman et al., 2021). In the present scenario, renewable energy sources are capturing the maximum possible part of the power generation field in place of traditional energy generation sources in the power system. The power generation field is continuously moving towards renewable energy sources to fulfil increased power demand. Renewable energy sources have various advantages such as being environmentally friendly, abundant sources, and freely and easily available. Different types of renewable energy generation sources like photovoltaic (PV) solar, wind energy, bio-energy, and ocean energy have proven their importance over conventional types due to these favourable features. Out of these several types of non-conventional energy sources, the applicability of PV solar and wind energy source is more recognised in the past few years (Liao et al., 2017; Painuly, 2001). These are not only environmentally friendly but also cost-effective and well-supported by different government schemes. They are established to mitigate increased power demand. Simultaneously, they have some key issues of power quality, energy management, stability, maximum possible power delivery and maximum efficiency (Ejgar and Momin, 2018; Aggarwal and Nijhawan, 2016). To overcome these key areas of issue, researchers are working on different control tactics in these areas. Intelligent control tactics based on soft computing are established as more useful to deal with these problems (Rahman et al., 2021). In literature, different types of control techniques have been implemented. In this paper, the control tactics based on soft computing and ANN tactic have been reviewed.

In this paper, the surveys on different types of control methods are presented in the following order:

1 classification of different soft computing-based control tactics for PV solar energy generation system

2 classification of different soft computing-based control tactics for wind energy generation system

3 performance analysis of ANN-based control tactic for PV solar energy generation system and wind energy generation system.

2 Artificial neural networks

An ANN is an autonomous, intelligent system and is popular as a nonlinear statistical data model. ANN is act-alike biological NNs. Neuron: the smallest unit of a neural network is interconnected for control purposes. The interconnection of neurons in the neural network is classified as:

1 single layer feed forward (SLFF) structure

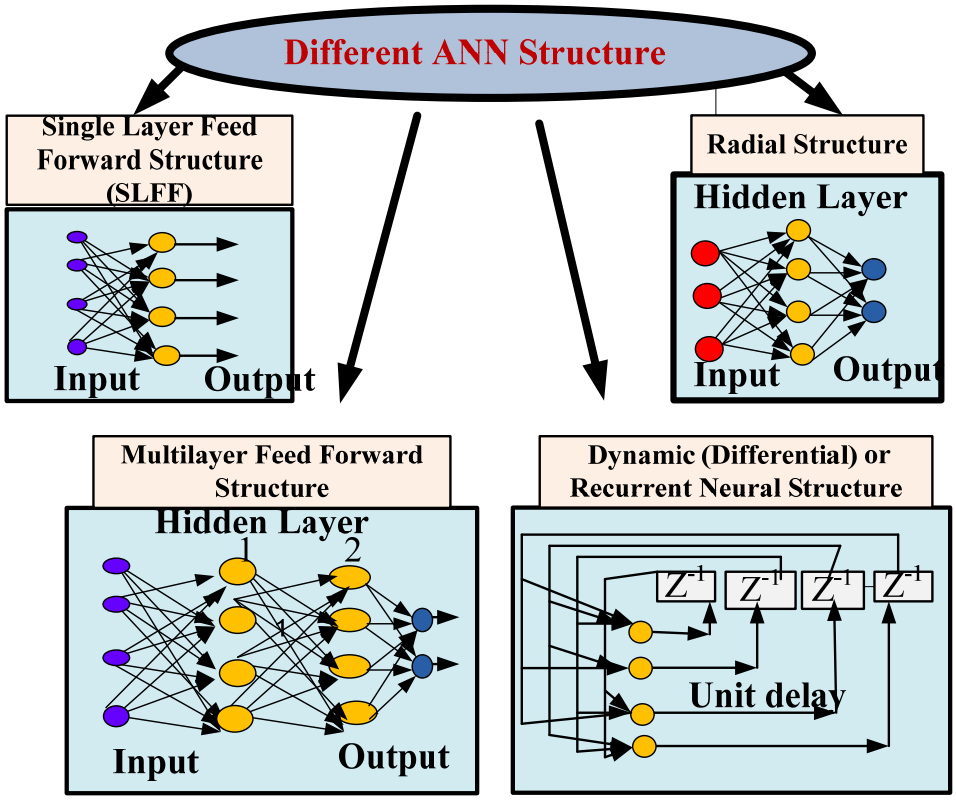
2 multilayer feed forward (MLFF) structure

3 radial structure

4 recurrent neural structure.

Figure 1 shows the classification of the different structures of ANN. From Figure 1, SLFF has a single layer and single neuron with adjustable weights. MLFF has one or more hidden layers with an output signal of neurons of each layer as input of another layer. The radial structure has three layers input, output and hidden layer. The recurrent type has one feedback loop (Chen et al., 2020).

Figure 1 Different ANN structure (see online version for colours)



ANN does not require mathematical modelling and deals with unpredictable, complex conditions. An ANN control scheme has been performed effectively and efficiently for numerous applications and problems. ANN has been applied in control applications with various merits in comparison to traditional control methods. ANN can provide the solution for a nonlinear system by approximating time changing system. ANN has many more advantages as well. It can learn from the data pattern provided by the user and tune for the specified system. For the dynamic system, it can automatically change parameters to perform efficiently. In the present scenario, a fully automated system, independent of

manual operation, and an intelligent system are required. In this context, ANN has attracted the researcher and increased the application area. This fulfils the main requirement of a control application as it is a smart and self-regulated system. In the ANN-based control technique, the user needs to set desired output. Then, a sample of data pattern has applied to train ANN. ANN changes its parameter automatically to reach the desired output. Therefore, this would be very beneficial when working parameters and conditions are changing continuously or conditions are unpredictable. This is the main reason that makes it a popular for renewable energy system. Due to these features, it fits as a famous control technique into the main requirement of a renewable energy system (Kalogirou, 2000; Mhatre et al., 2015).

In the area of renewable energy generation, the control ability of ANN is checked through modelling in a MATLAB environment before practical implementation. To implement an ANN-based control technique for a system in MATLAB following are the steps (Mhatre et al., 2015):

1 *Sample of datasets:* The data input is applied to the ANN model. These are the sample datasets used for training of ANN model.

2 *Configure according to the user requirement:* This process is referred to as pre-processing. In this process, the user selects and set configuration values such as the number of hidden layers, input dataset and output datasets for ANN, the training function, number of the epoch, and so on. This is chosen as per the user's requirement.

3 *Training and evaluation:* In this process, the user trains the ANN for a data pattern. In this 20 of hundredth is used for validation and another 20 of hundredth is used for testing. This process is lead to minimising the error to maximise the output.

3 Literature survey

In this section, a detailed survey on various control techniques for PV solar energy generation system, wind energy generation system, and analysis of performance of ANN-based control tactic for PV solar energy generation system and wind energy generation system is presented.

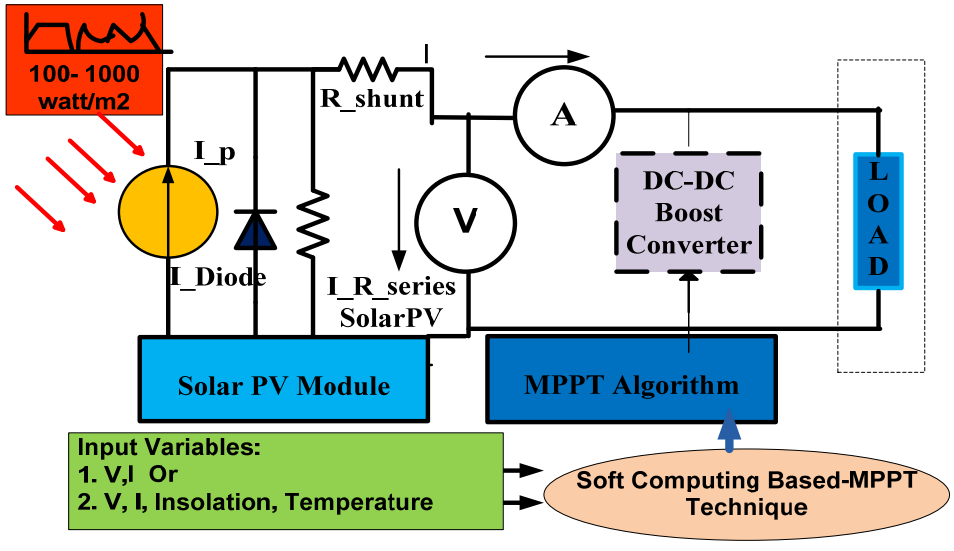
3.1 Classification of different soft computing-based control tactics for PV solar energy generation system

Solar PV energy generation system is considered too inconsequential to produce adverse effects on the environment and hence the ecosystem (Ejgar and Momin, 2018). Its power output is varied according to internal and external determinants such as circuit parameters and insolation, temperature, shedding, dust deposition, and so on (Painuly, 2001). In this context, control tactics are used to enhance the applicability of solar PV systems. Therefore, an efficient MPPT control scheme is used to trace the maximum available power for a generation. An efficient MPPT control technique boosts the tracking speed to get maximum power output and improves output efficiency.

PV solar energy system is shown in Figure 2. Here, maximum power is provided to the load through a boost converter. Here, soft computing-based MPPT algorithms follow

the point at which power is maximum (Sumathi et al., 2015; Abd Elaziz et al., 2022). MPPT algorithm is a control technique, in which by using programming tries to set the impedance seen by the PV array to reach near or exactly at the condition of maximum power under varying weather conditions like changing irradiance, temperature and load. Different MPPT methods were proposed and practically applied to optimise solar PV performance. Then, these methods were evaluated to check the solar PV performance to increase the power output under variable environmental conditions. In the literature, the previous survey and comparison were studied concerning the control technique depending upon electro-mechanical equipment or sun trackers and electrical equipment. The further review study classified the different MPPT methods according to input variables. In this paper, the classification according to soft computing-based MPPT methods is presented. The classification is shown in Figure 3.

Figure 2 PV solar energy system with soft computing-based MPPT technique (see online version for colours)



All soft computing-based MPPT control tactics are categorised into two main groups: traditional and intelligent control techniques. Further, an intelligent control system is subcategorised as novel-intelligent and hybrid-intelligent type control techniques. In these different types of techniques, input variables may be past recorded or offline data and actual or online data (Bollipo et al., 2021; Ram et al., 2017). These inputs are current, voltage, insolation and temperature. These data are direct or indirect variables. Current and voltage are known as direct variables. Insolation and temperature are known as indirect variables.

3.1.1 Traditional tactics

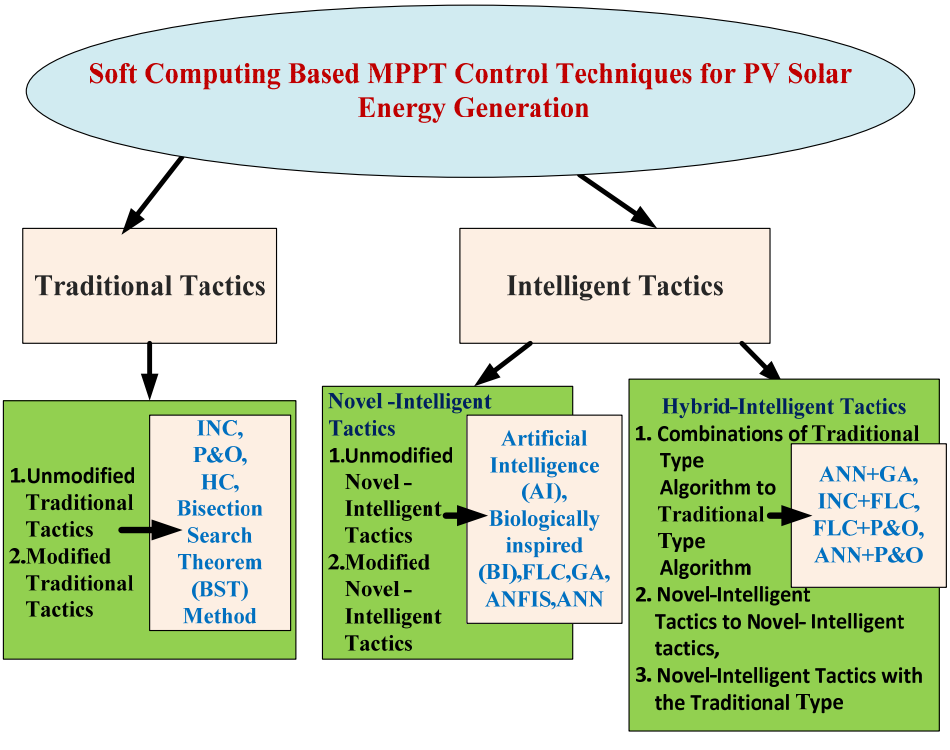
These are conventional control methods and are referred to as soft computing-based traditional control tactics. In this type, MPPT control tactics are categorised into two parts:

1 unmodified traditional tactics

2 modified traditional tactics.

In the first part, all conventional MPPT control tactics depending upon direct variables are classified under unmodified traditional tactics. In the second part, all conventional MPPT control tactics depending upon direct and indirect variables are classified as modified traditional tactics. In unmodified traditional MPPT control methods, the algorithm parameters are not changed according to a sudden change in input variables. Therefore, conventional unmodified methods cannot respond accordingly to the abrupt change in environmental conditions, disturbance, and hence solar PV systems. This class of techniques has a drawback that it cannot differentiate local and global points of maxima on power and voltage characteristics thus it gets trapped at the local point of maxima. Therefore, solar PV systems using these techniques will have power loss at the output during the maximum power extracting process. This type of class depends on sampled input variables rather than the PV model to extract maximum power. Another type of traditional tactic is modified traditional tactics. In this type of class, the main emphasis is on controlling external variables and hence optimises the operation of unmodified traditional tactics. In this type, current, voltage, insolation, and temperature are used as input variables to remove unwanted power oscillation. These traditional tactics include perturb and observe (P&O), INC, HC, BST, etc. (Liu et al., 2008; Jain et al., 2018; Ali et al., 2020).

Figure 3 Classification of different soft computing-based control tactics for PV solar energy generation system (see online version for colours)



3.1.2 Intelligent tactics

This type of soft computing intelligent tactic is further classified as novel-intelligent tactic and hybrid-intelligent tactic.

3.1.2.1 Novel-intelligent tactic

This is further classified into two categories according to the data input used in the algorithm. In the first category, input variables are voltage and current and this type is classified as an unmodified novel-intelligent tactic. In the second category, input variables are voltage, current, insolation and temperature. This type is referred to as a modified novel-intelligent tactic. Novel-intelligent algorithms include artificial intelligence and biologically inspired technique. This technique can reach the global point of maxima without power loss during maximum power tracking. Even MPPT techniques like a bee colony, bat, and ant colony optimisation algorithm of this class were used to find the global point of maxima and to get maximum power under shedding conditions. The cuckoo search was used to get better performance and high convergence speed. Memetic salp swarm algorithm (MSSA) was applied with fast-changing insolation and temperature data samples and fast convergence speed was obtained. Novel-intelligent tactics include AI and BI. In class BI, different control algorithms such as fuzzy logic control (FLC), GA, ANFIS, and ANN have been used (Ali et al., 2020; Phan et al., 2010).

3.1.2.2 Hybrid-intelligent tactic

Hybrid-intelligent tactic is the hybrid combination of traditional with traditional, novel-intelligent algorithms with novel-intelligent algorithms, and traditional with novel-intelligent algorithms. This is further categorised as an unmodified hybrid-intelligent tactic and a modified hybrid-intelligent tactic. The input variables for the unmodified hybrid-intelligent tactic are voltage and current. The input variables for the modified hybrid-intelligent tactic are voltage, current, insolation and temperature. This includes a hybrid combination of ANN with GA, INC with FLC, FLC with P&O, ANN with P&O, etc. (Bollipo et al., 2021; Abdelouadoud and Abdelhamid, 2013). This family is the combination of novel-intelligent tactics with novel-intelligent tactics, novel-intelligent tactics with the conventional type algorithm, and conventional type algorithm with conventional type algorithm. These were proposed and successfully applied to overcome drawbacks and to use the features to fulfil our requirements. FLC and P&O tactics were designed and applied under fast-changing environmental conditions and for steady conditions also. Similarly, the hybrid combination of FLC with INC was proved the superior characteristics. This new combination has features of high speed, less number of fuzzy rules, acting as pure fuzzy structures, and high accuracy. A few drawbacks high cost, and complexity issues were reported. Similarly, the hybrid combination of ANN algorithms with the traditional P&O and INC algorithm was used.

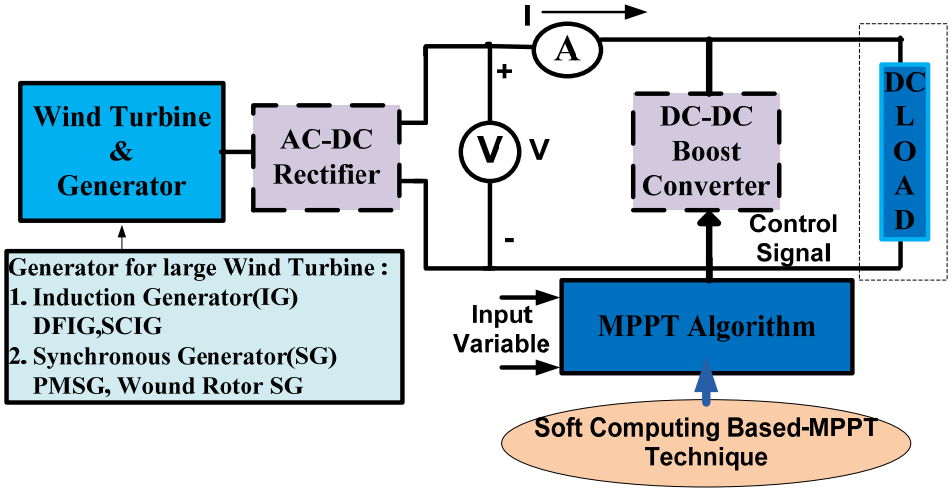
3.2 Classification of different soft computing-based control tactics for wind energy generation system

A wind energy system is an emerging alternative source of energy due to its eco-friendly and economical features. Nowadays, this is a famous renewable energy source (Aggarwal

and Nijhawan, 2016). Output power and efficiency of wind energy systems are being tried to be increased by using different soft computing-based control methods. Many research articles were presented about various MPPT control techniques to get maximum power continuously without affecting by environmental conditions.

Figure 4 depicts the wind energy system. Here, a generator converts mechanical power from the wind turbine into electrical power and supplies it at the desired level to the load connected through a rectifier and boost converter (Sumathi et al., 2015). Induction generator and synchronous generator are the two types of generators used in the wind energy conversion system as shown in Figure 4. The generation of maximum power is achieved through the MPPT algorithm. Here, soft computing-based MPPT algorithms follow and extract the maximum power for change in wind conditions. MPPT algorithm is a control technique, in which by using programming tries to reach near or exactly at the condition of maximum power under varying weather and wind conditions. In literature, various MPPT algorithms are used. All have their pros and cons. MPPT technique selection is dependent on several parameters, efficiency, speed, complexity, and so on (Sachan et al., 2017). Figure 5 is showing the classification of different soft computing-based MPPT techniques.

Figure 4 Wind energy system with soft computing-based MPPT technique (see online version for colours)



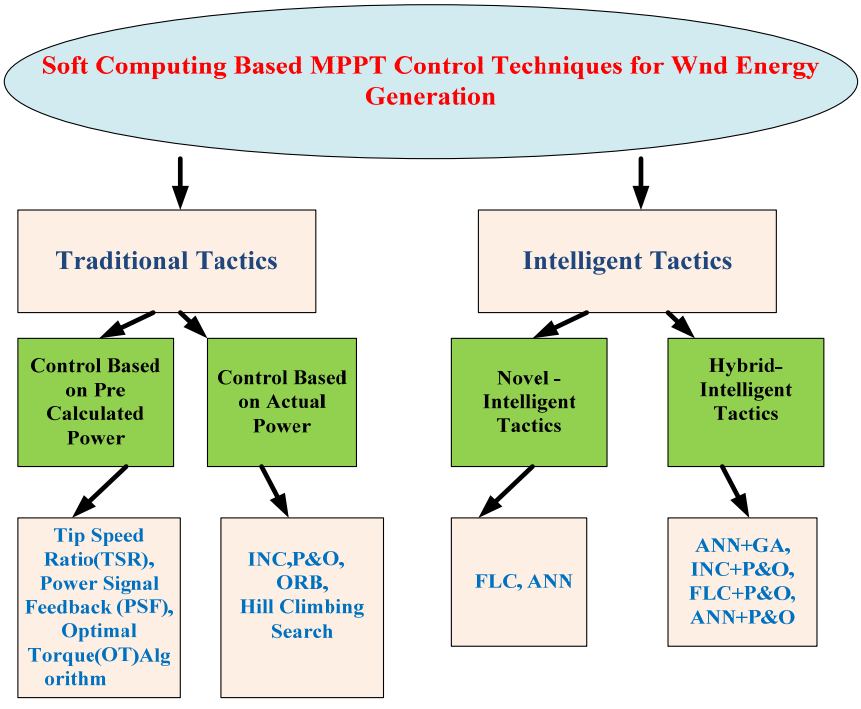
In the literature, there are two types of soft computing-based MPPT methods: traditional tactics and intelligent tactics.

3.2.1 Traditional tactics

Traditional tactics are further categorised according to the prior knowledge about the characteristics of the generator used and simultaneously about the environmental conditions. Therefore, there are two types of traditional tactics. The first class is control based on the pre-calculated power. Another class is control based on actual power. Control based on pre-calculated power class includes tip speed ratio (TSR), power signal feedback (PSF) and optimal torque control (OTC) (Singh and Ouhrouche, 2011; Mishra

et al., 2015; Thongam et al., 2011). This class of soft computing-based MPPT algorithms is dependent on previous information about generators and weather conditions. In this, the information about power is determined from the wind speed characteristics.

Figure 5 Classification of different soft computing-based control tactics for wind energy generation system (see online version for colours)



Control based on actual power class includes P&O, hill climbing search (HCS), optimal relation-based (ORB) and FLC. This class of soft computing-based MPPT algorithms is independent of the previous information about generators and weather conditions (Zebraoui and Bouzi, 2018). In this, the power is directly inspected to operate the turbine at the point of the maximum value of power. In the literature, P&O were reported with multi-variable for various generators in the wind farm. It was advantageous to use this technique in comparison to P&O as it reduced installation costs (Hemanth Kumar et al., 2018).

3.2.2 Intelligent tactics

From the survey, intelligent tactics are further categorised as novel-intelligent tactics and hybrid-intelligent tactics. Novel-intelligent tactics include ANN-based MPPT algorithm and FLC-based algorithm.

In ANN, three layers hidden, input, and output are used. In the ANN and fuzzy logic controller-based algorithm, maximum power is achieved. In the FLC-based algorithm, maximum power was achieved with reduced oscillation near to point of maximum power.

This is possible due to a feature of the controller of fast-changing controller variables with fast-changing environmental conditions. Therefore, it was found that this controller can work in steady and fast-changing environmental conditions. Its performance was dependent on user knowledge to design and decide rules, membership functions, etc. Similar to PV solar, in the wind, an energy generation hybrid combination of traditional to traditional, traditional to intelligent was presented. A hybrid combination of ANN and P&O, FLC and P&O, was proposed as a hybrid-intelligent tactics class (Sachan et al., 2017; Abdullah et al., 2012; Mousa et al., 2021). To overcome the drawbacks of traditional algorithm-based MPPT control techniques various other algorithms such as cuckoo search, particle swarm optimisation, GA algorithm, etc. were used and implemented as a hybrid combination with the traditional algorithm. A hybrid combination of FLC with traditional P&O was implemented to improve conversion efficiency and to get maximum power. To track maximum power with correct direction during abrupt and fast changes in wind speed, the INC algorithm with P&O is used (Sachan et al., 2017; Singh and Ouhrouche, 2011; Thongam et al., 2011; Zebraoui and Bouzi, 2018; Abdullah et al., 2012; Mousa et al., 2021; Sitharthan et al., 2020; Salem et al., 2019; Kumar and Chatterjee, 2016).

3.3 Performance analysis of ANN-based control tactic for PV solar energy generation system and wind energy generation system

Over the past few years, ANN-based control techniques are showing better performance in many control applications of renewable energy systems. In this paper, the performance of ANN-based MPPT control methods is presented for PV solar and wind energy generation system. ANN-based control techniques are replacing traditional control techniques. The aim of this article is to explore the effectiveness and controllability of ANN-based techniques over other soft computing control techniques (Rahman et al., 2021; Chen et al., 2020; Kalogirou, 2000).

For PV solar energy generation systems, ANN-based control techniques are implemented for various applications. Some of the application areas are solar irradiation forecasting for a specific area as per application of PV solar plant setup, optimal sizing, and optimal sizing to reduce cost, get maximum power and increase the efficiency of PV solar energy system. Here, control methods used to harvest the maximum power and increase the efficiency of PV solar energy system has been explored. The various hybrid combinations of conventional to conventional, novel-intelligent to novel-intelligent, and novel-intelligent tactics to conventional type algorithm came into the picture to utilise the advantages of both the class and to reduce the drawback of each type. ANN-based control tactic is the one of techniques from the novel-intelligent class. The hybrid combination can enhance the capability of each technique by harnessing the required property or cumulatively. The hybrid combination of ANN algorithms with the traditional P&O and ANN with the INC algorithm was demonstrated. These new combinations were applied and proved the optimum output in comparison to the traditional techniques (Bollipo et al., 2021; Ali et al., 2020; Phan et al., 2010; Syafaruddin et al., 2009; Younis et al., 2012).

Table 1 Comparison between ANN and other soft computing-based techniques for PV solar energy systems

S. no.	*Parameters*	*Comparison between ANN and other soft computing-based techniques*				
		P&O	*INC*	*ANN*	*FLC*	*Hybrid (ANN + GA, INC + FLC, FLC + P&O, ANN + P&O)*
1	Pre-information of data	Not required	Not required	Required	Required	Not required
2	Convergence speed	Varies	Varies	High	Medium-high	High
3	Behaviour under fast changing weather conditions	Found moderate performance	Found moderate performance	Better performance	Better performance	Found moderate performance
4	Oscillations near or at the point of maximum power	Reported	Reported low	Less	Less but reported	Less
5	The efficiency with less power loss	Medium	Medium-high	Very high	Medium	High
6	Complexity	Less	Medium	Medium	Medium-high	Medium
7	Differentiate global and local point of maxima	Not	Not	Yes	Not	Depends

Table 2 Comparison between ANN and other soft computing-based techniques for wind energy generation system

S. no.	*Parameters*	*Comparison between ANN and other soft computing-based techniques*					
		Traditional technique – control based on the pre-calculated power (TSR, OTC, PSF)	*Traditional technique – control based on actual power (P&O,ORB and HCS)*	*Multi-variable P&O*	*ANN*	*FLC*	*Hybrid (ANN + GA, INC + FLC, FLC + P&O, ANN + P&O)*
1	Pre-information of data	Not required for TSR Required for PSF and OTC	Not required	Not required	Required	Required	Not required
2	Parameter dependency	Yes	Not reported	Not required	Yes	Yes	Not reported
3	Behaviour under fast changing weather conditions	Found moderate performance	Found moderate performance	Reported less in comparison to NN	Better performance	Better performance	Found moderate performance
4	Oscillations near or at the maximum power point	Not found	Reported	Reported	Not found	Not found	Depends
5	The efficiency with less power loss	Higher	Low	Less than NN	Higher	Medium	Very high
6	Complexity	less	less	More than P&O	more	more	In between

In the field of wind energy generation, the ANN-based control technique is showing acceptable and efficient performance in tracking a point of maximum power under unpredictable factors as well as fast-changing weather conditions. ANN-based control technique has been implemented in many applications. Some of the applications are to control pitch angle, maximum power generation, maximum efficiency with less power loss, wind speed prediction, and so on. Besides the traditional control methods, the ANN-based control technique seems to be more efficient in getting maximum power. In ANN, four types of structures SLFF, MLFF, recurrent, and radial structure were reported. Maximum power generation with reduced oscillation is possible by ANN-based technique. This is due to its capability of changing parameters with sudden changes in wind speed. This is how it can perform better in comparison to the other technique. The hybrid combination of the ANN with the P&O algorithm regulates the power and eliminates the slow response which is the behaviour of traditional MPPT techniques. Application of ANN was reported to control isolated and a grid-connected hybrid combination of PV solar and wind energy generation (Sachan et al., 2017; Singh and Ouhrouche, 2011; Mishra et al., 2015; Thongam et al., 2011; Sitharthan et al., 2020; Kumar and Chatterjee, 2016).

The comparison between ANN-based control techniques and other soft computing-based techniques for PV solar energy generation systems is presented in Table 1. The comparison between ANN-based control techniques and other soft computing-based techniques for wind energy generation systems is demonstrated in Table 2.

4 Conclusions

From the studies, the ANN-based MPPT control technique has proved better controllability and efficient performance in comparison to the other soft computing-based conventional control tactics. ANN is replacing the other soft computing-based control tactics by securing an important position due to its decision ability like a human. It has the prediction and interpretation capability of weather changes for PV solar energy generation and wind energy generation systems for an area. Under fast-changing conditions, it can generate power output at maximum value with less oscillation at the maximum power point. In the case of more than one LPMP, ANN-based MPPT is intelligent enough to differentiate GPMP and LPMP on complex nonlinear PV curves in comparison to the conventional MPPT technique. According to the unknown extraneous factors and weather conditions, it can change its parameters and perform better to generate maximum power and improve efficiency.

ANN has been implemented for MPPT control as well as for other controlling applications in the PV solar and wind energy generation field. However, there are many application areas where ANN needs to be applied. It will be used for other types of renewable sources such as bio-energy systems and ocean energy systems to increase the applicability of the ANN-based control technique and to make it more famous in the field of renewable energy sources. Taking all mentioned features, it can be concluded that ANN might be a good control technique for other types of renewable sources.

References

Abd Elaziz, M., Almodfer, R., Ahmadianfar, I., Ibrahim, I.A., Mudhsh, M., Abualigah, L., Lu, S., Abd El-Latif, A.A. and Yousri, D. (2022) 'Static models for implementing photovoltaic panels characteristics under various environmental conditions using improved gradient-based optimizer', *Sustain. Energy Technol. Assessments*, Vol. 52, Part B, p.102150.

Abdelouadoud, L. and Abdelhamid, L. (2013) '216 comparison of P&O and fuzzy MPPT methods for photovoltaic system', *Solar Energy*, Vol. 112, No. 1, pp.1–11.

Abdullah, M.A., Yatim, A.H.M., Tan, C.W. and Saidur, R. (2012) 'A review of maximum power point tracking algorithms for wind energy systems', *Renew. Sustain. Energy Rev.*, Vol. 16, No. 1, pp.3220–3227.

Aggarwal, S. and Nijhawan, P. (2016) 'Review on solar and wind power potential in India', in *2016 7th India International Conference on Power Electronics (IICPE)*, IEEE, pp.1–5.

Ali, A., Almutairi, K., Padmanaban, S., Tirth, V., Algarni, S., Irshad, K., Islam, S., Zahir, M.H., Shafiullah, M. and Malik, M.Z. (2020) 'Investigation of MPPT techniques under uniform and non-uniform solar irradiation condition – a retrospection', *IEEE Access*, Vol. 8, No. 1, pp.127368–127392.

Bollipo, R.B., Mikkili, S. and Bonthagorla, P.K. (2021) 'Hybrid, optimal, intelligent and classical PV MPPT techniques: a review', *CSEE J. Power Energy Syst.*, Vol. 7, No. 1, pp.9–33.

Chen, Y., Song, L., Liu, Y., Yang, L. and Li, D. (2020) 'A review of the artificial neural network models for water quality prediction', *Applied Sciences*, Vol. 10, No. 17, p.5776.

Ejgar, M. and Momin, B. (2018) 'Solar plant monitoring system: a review', *Proc. Int. Conf. Comput. Methodol. Commun. ICCMC 2017*, January, pp.1142–1144.

Grossi, E. and Buscema, M. (2007) 'Introduction to artificial neural networks', *Eur. J. Gastroenterol. Hepatol.*, Vol. 19, No. 12, pp.1046–1054.

Hemanth Kumar, M.B., Saravanan, B., Sanjeevikumar, P. and Blaabjerg, F. (2018) 'Review on control techniques and methodologies for maximum power extraction from wind energy systems', *IET Renewable Power Generation*, Vol. 12, No. 14, pp.1609–1622.

Jain, K., Gupta, M. and Kumar Bohre, A. (2018) 'Implementation and comparative analysis of PO and INC MPPT method for PV system', *India Int. Conf. Power Electron. IICPE*, December, pp.1–6.

Kalogirou, S.A. (2000) 'Artificial neural networks in renewable energy systems applications: a review', *Renew. Sustain. Energy Rev.*, Vol. 5, No. 4, pp.373–401.

Kumar, D. and Chatterjee, K. (2016) 'A review of conventional and advanced MPPT algorithms for wind energy systems', *Renew. Sustain. Energy Rev.*, Vol. 55, No. 1, pp.957–970.

Liao, S., Yao, W., Han, X., Wen, J. and Cheng, S. (2017) 'Chronological operation simulation framework for regional power system under high penetration of renewable energy using meteorological data', *Appl. Energy*, Vol. 203, No. 1, pp.816–828.

Liu, F., Duan, S., Liu, F., Liu, B. and Kang, Y. (2008) 'A variable step size INC MPPT method for PV systems', *IEEE Trans. Ind. Electron.*, Vol. 55, No. 7, pp.2622–2628.

Mhatre, M.S., Siddiqui, D., Dongre, M. and Thakur, P. (2015) 'A review paper on artificial neural network: a prediction technique', *Int. J. Sci. Eng. Res.*, Vol. 6, No. 12, pp.161–163.

Mishra, S., Shukla, S., Verma, N. and Ritu, R. (2015) 'Comprehensive review on maximum power point tracking techniques: wind energy', *Int. Conf. Commun. Control Intell. Syst. CCIS 2015*, pp.464–469.

Mousa, H.H.H., Youssef, A.R. and Mohamed, E.E.M. (2021) 'State of the art perturb and observe MPPT algorithms based wind energy conversion systems: a technology review', *Int. J. Electr. Power Energy Syst.*, Vol. 126, No. 1, p.106598.

Painuly, J.P. (2001) 'Barriers to renewable energy penetration: a framework for analysis', *Renew. Energy*, Vol. 24, No. 1, pp.73–89.

Phan, Q.D., Le, D.K., Hong, H.L., Le, M.P. and Vu, N.T.D. (2010) 'The new MPPT algorithm using ANN-based PV', *2010 Int. Forum Strateg. Technol. IFOST 2010*, pp.402–407.

Rahman, M.M., Shakeri, M., Tiong, S.K., Khatun, F., Amin, N., Pasupuleti, J. and Hasan, M.K. (2021) 'Prospective methodologies in hybrid renewable energy systems for energy prediction using artificial neural networks', *Sustain.*, Vol. 13 No. 4, pp.1–28.

Ram, J.P., Rajasekar, N. and Miyatake, M. (2017) 'Design and overview of maximum power point tracking techniques in wind and solar photovoltaic systems: a review', *Renew. Sustain. Energy Rev.*, Vol. 73, No. 4, pp.1138–1159.

Sachan, A., Gupta, A.K. and Samuel, P. (2017) 'A review of MPPT algorithms employed in wind energy conversion systems', *J. Green Eng.*, Vol. 6, No. 4, pp.385–402.

Salem, A.A., Aldin, N.A.N., Azmy, A.M. and Abdellatif, W.S.E. (2019) 'A fuzzy logic-based MPPT technique for PMSG wind generation system', *Int. J. Renew. Energy Res.*, Vol. 9, No. 4, pp.1751–1760.

Singh, J. and Ouhrouche, M. (2011) 'MPPT control methods in wind energy conversion systems', *Fundamental and Advanced Topics in Wind Power*, Vol. 15, No. 1, pp.339–360.

Sitharthan, R., Karthikeyan, M., Sundar, D.S. and Rajasekaran, S. (2020) 'Adaptive hybrid intelligent MPPT controller to approximate effectual wind speed and optimal rotor speed of variable speed wind turbine', *ISA Trans.*, Vol. 96, No. 1, pp.479–489.

Sumathi, S., Kumar, L.A. and Surekha, P. (2015) *Solar PV and Wind Energy Conversion Systems: An Introduction to Theory, Modeling with MATLAB/SIMULINK, and the Role of Soft Computing Techniques*, Vol. 1, Springer, Switzerland.

Syafaruddin, Karatepe, E. and Hiyama, T. (2009) 'Artificial neural network-polar coordinated fuzzy controller based maximum power point tracking control under partially shaded conditions', *IET Renew. Power Gener.*, Vol. 3, No. 2, pp.239–253.

Thongam, J.S., Ouhrouche, M., Ragheb, M. and Ragheb, A.M. (2011) 'MPPT control methods in wind energy conversion systems, fundamental and advanced topics in wind power', *Fundamental and Advanced Topics in Wind Power*, Vol. 15, No. 1, pp.339–360.

Younis, M.A., Khatib, T., Najeeb, M. and Mohd Ariffin, A. (2012) 'An improved maximum power point tracking controller for PV systems using artificial neural network', *Prz. Elektrotechniczny*, Vol. 88, No. 3b, pp.116–121.

Zebraoui, O. and Bouzi, M. (2018) 'Comparative study of different MPPT methods for wind energy conversion system', *IOP Conf. Ser. Earth Environ. Sci.*, Vol. 161, p.012023.