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Research paper

A MPPT strategy based on cuckoo search for wind energy conversion system

C. Centhil Kumar [1]*, I. Jacob Raglend[2]

[1]*Department of Electronics and Instrumentation Engineering, Noorul Islam Centre for Higher Education, Kanyakumari, Tamilnadu, India*
[2]*School of Electrical Engineering, Vellore Institute of Technology, Vellore, Tamilnadu, India*
**Corresponding author E-mail: emailcenthil@gmail.com*

Abstract

The WECS based Doubly Fed Induction Generator (DFIG) system is presented in this paper which includes different MPPT control strategies for a grid connected system. The GSC gives the flow of power from the rotor part of DFIG up to the grid and the modulation of DC voltage. Here the cuckoo search algorithm based on MPPT is designed, to obtain a higher power from the changing speed wind turbine. The algorithms such as Perturb and Observe (P&O), Proportional Integral (PI) control and Fuzzy Logic Controller (FLC) are compared and their performances are evaluated. To design and develop the cuckoo search optimization based on MPPT for WECS, and to obtain optimum voltage regulation and power, thus improving the working performance, reducing the domain time and minimizing the performance indices. To simulate the different MPPT control methods, MATLAB/Simulink environment is used here.

Keywords:*Wind Turbine; Doubly Fed Induction Generator; Fuzzy Logic Controller; MPPT; Cuckoo Search Algorithm.*

1. Introduction

Nowadays, extensive use of conventional energy sources can be replaced by non-conventional energy sources (wind, solar etc,) to generate electricity. The most dependent and essential source of renewable energy is wind energy source. This demands additional forwarding capacity and good means of maintaining system reliability. The power which is generated from the wind turbine is the optimum as compared to the energy that is generated by the PV source, because of the cost per kilo watt in relation with seconds [1]. In recent times, the most commonly used WECS based on DFIG is employed, because it is used in variable speed applications, the subtraction of mechanical stresses, acoustic noises and improving the quality of power [2].
In the past few years, the hybridization of MPPT method and classical PID controller with fuzzy logic control methods are employed for increasing the performance of PID controller without altering the system stability [6]. Huge numbers of papers have been published recently on intelligent controllers such as Artificial Neural Network (ANN) controller, evolutionary algorithms-based controller and fuzzy control [7].
In order to attain the higher power from wind energy, several control methods have been developed here [8, 9], such as fuzzy logic control, integrator back stepping, feedback linearization method, neural networks and control of sliding mode. The disadvantages of these methods are that they require the comprehension of the optimal power characteristic and wind measurement. So it leads to the sensitivity of turbine characteristics variation and uncertainties in wind measurement.
For attaining higher power different adaptive control techniques are delivered in wind energy conversion system [13]. A suitable fuzzy control method which uses radial basis function for wind turbine based on PMSG was suggested, which worked profitably with the unsure parameters of turbine [14]. In both works, a sliding supervisory term is presented. A disadvantage of this technique is the bounded premise made on the gain control, its derivative and on its fault on structure [13], the dynamics vector [14] and wellspring of chattering and complicacy.
The method of HCS is suggested for PV systems, it seeks the higher turbine power by disturbing the speed of the wind turbine [8, 16]. The important limitation of this is, the time of convergence depends on the pre-existing space of the system working point and the disturbance [10]. P&O method has been mostly used due to its built in easy and simple method. P&O algorithms have system variables as control inputs for the MPPT like the dc-link voltage and the duty cycle. Limitation of this algorithm is less system price results in high reliability by subtracting the need for speed of shaft sensing and the convergence of it is very less.
A turbine is generating the power from wind by using a novel sliding mode control [12]. It contains direct control of torque and grid linked for changing speed WECS on the basis of PMSG. The suggested technique can deliver a best control results for a wind energy control system on the basis of PMSG. It should be pointed that most of the heuristic-based control algorithms (FLC, MRAC and ANN methods) can get better Control performances. Limitation of this method, it takes a more time for these algorithms to train, because these control algorithms are usually mathematically critical. Therefore, it is not suitable for engineering applications.
Meta-heuristic algorithm is called grouped grey wolf optimizer. It can achieve MPPT with an improved FRT capability simultaneously [3]. In addition, [4] adopted particle swarm optimizer (PSO) to enhance the building energy performance. Moreover, a GA was developed to decrease the energy consumption of the hybrid storage system of energy in the electric vehicle [5].
The aim of this paper is on effective use of MPPT techniques and the optimization of control parameters on the grid side converter, thereby making a high performance WECS. The main objective of

this work is associated with voltage regulation at the grid side, to reduce the settling time, rise time, overshoot and undershoot problems, low transient response and high computational complexity These have been achieved by using P&O algorithm, PI controller, FLC and Cuckoo search Optimization.

2. Modeling of wind energy conversion system

The WECS configuration is given in the Fig. 1. It consists of wind turbine, gearbox, DFIG and two-level back-to-back converter. The wind turbine is used to convert the aerodynamic power into the mechanical power. Then, this power is transformed to the DFIG. The DFIG-WT is the changing speed wind turbine; it does not need a full-size converter to deliver the grid with an unchanged power frequency and capability of power factor is unity. The two-level back to back converter is used to adjust the reactive and active powers generated by the WECS to the grid. The GSC is used here to change the DC bus between these two converters and its power factor is unity. DFIG is preferred for the change of wind and rotor winding which has resulted in lower cost of converter and low power loss.

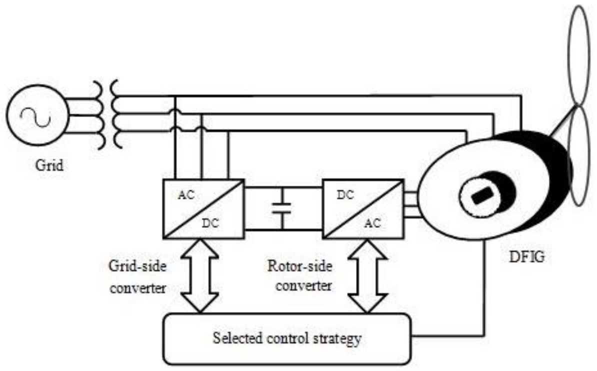


Fig. 1: WECS Configuration.

2.1. Modeling of the DFIG

The equations of DFIG are obtained from the model of Park shown in a reference frame d-q circulating at the synchronous speed ω_s. The conversion system of electrical energy is explained by the induction machine equation by DFIG model and the model of turbine.

a) The Turbine Model

The power of aerodynamic P observed by the wind turbine is shown by:

$$P = \frac{1}{2}\pi\rho R^2 Cp(\lambda)v^3 \tag{1}$$

Here the speed ratio of tip λ is

$$\lambda = \frac{R\omega}{v} \tag{2}$$

V is the wind, ρ is the density of air, R is the rotor radius, and Cp is the coefficient of power. λ is the ratio of turbine blades tip speed to wind speed and β is the turbine blades rotational speed.

The rotor power or aerodynamic power is given by

$$P = T_m.\omega \tag{3}$$

Here the aerodynamic torque is T_m and rotor speed of wind turbine is ω.

The below given reduced model is changed for the turbine:

$$J\frac{d\omega}{dt} = T_m - T_{em} - K\omega \tag{4}$$

Here generator electromagnetic torque is T_{em}, total inertia of turbine is J, and total external damping of turbine is K. The reactive and active rotor and stator powers are given by:

$$\begin{cases} P_s = V_{sd}I_{sd} + V_{sq}I_{sq} \\ Q_s = V_{sq}I_{sd} - V_{sd}I_{sq} \\ P_r = V_{rd}I_{rd} + V_{rq}I_{rq} \\ P_s = V_{rq}I_{rd} - V_{rd}I_{rq} \end{cases} \tag{5}$$

For improving efficiency of the system, speed of system is adjusted as a function of wind speed to increase the output power.

b) The DFIG Model

The control system is explained in the synchronous d-q frame attached to both the voltage of stator and the flux of stator. The rotating frame d-q is shown by

$$\begin{cases} V_{sd} = R_s I_{sd} + \frac{d\Phi_{sd}}{dt} - \omega_s.I_{sq} \\ V_{sq} = R_s I_{sq} + \frac{d\Phi_{sq}}{dt} + \omega_s.I_{sd} \\ V_{rd} = R_r I_{rd} + \frac{d\Phi_{rd}}{dt} - \omega_r.I_{rq} \\ V_{rq} = R_r I_{rq} + \frac{d\Phi_{rq}}{dt} + \omega_r.I_{rd} \\ T_{em} = P\,M(I_{rd}I_{sq} - I_{rq}.I_{rd}) \\ \Phi_{sd} = L_s I_{sd} - m.L_m.I_{rd} \\ \Phi_{sq} = L_s I_{sq} - m.L_m.I_{rq} \\ \Phi_{rd} = L_r I_{rd} - m.L_m.I_{sd} \\ \Phi_{rq} = L_r I_{rq} - m.L_m.I_{sq} \end{cases} \tag{6}$$

Where V is the voltage, I the current, Φ is the flux, R is the resistance, L is inductance, M is the mutual inductance, T_{em} is the electromagnetic torque, and P is the pair number of the pole.

2.2. Modelling of DC/DC converter

Boost converter is used in this paper. Input voltage is step up by using Boost converter. Duty cycle is varied by controlling the output voltage. Because of the duration of the switches, the boost converter is operated in two different modes. When closing of switch takes place, the energy is stored by inductor and the energy is released by capacitor. When opening of switch takes place, they will do the opposite functions. The model circuit of the boost converter is given in Fig. 2.

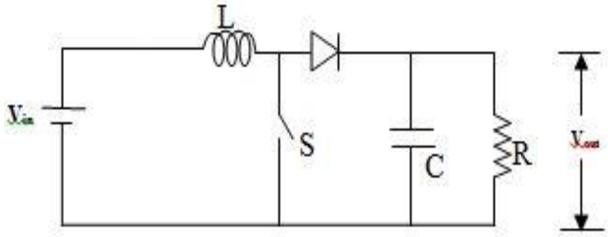


Fig. 2: Boost Converter Circuit Model.

The average output voltage is given by

$$V_{out} = \frac{V_{in}}{1-D} \tag{7}$$

Hereoutput Voltage isV_{out}, the input voltage is $V_{in}$and the duty cycle is D of the converter switch.

3. Control strategies of WCES

The WECS efficiency is improved by MPPT technique is used according to MPP theorem. Power of output at any circuit can be increased by changing the impedance of source equals the impedance of load. Because of this the MPPT algorithm is drafted corresponding to the problem of impedance matches. The boost Converter is applied here as impedance matching device between output and input by altering the converter circuit duty cycle. Output voltage of this converter depends up on this duty cycle, because of this; the MPPT is used here to find the duty cycle for obtaining the higher output voltage. As output voltage is raising then the power will also increase.

3.1. PI controller

In MPPT method based on PI, a signal of error is produced by the usage of the DC voltage reference and actual DC voltage. The signal of error is given to the PI Controller, thus the output signal is acquired. After this, the output signal is matched with the triangular waveform with frequency repetition to give a duty cycle which will work the DC/DC Converter switch therefore; the higher power is acquired based upon the change of wind speed. Fig. 3. represents the block diagram of PI controller.

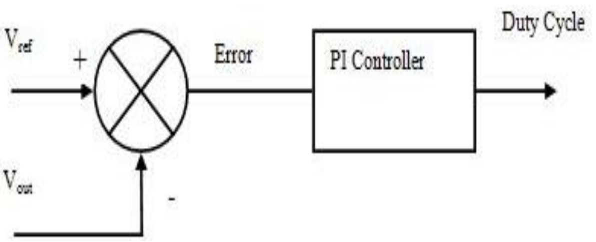


Fig. 3: PI Controller.

The equation used for PI controller is given below

$$D(s) = \left(K_p + {K_i}/{s}\right) * E(s) \tag{8}$$

Where, K_p is proportional parameter and K_i is integral parameter.The error between reference voltage and output voltage is $E(s)$and duty cycle is D(s).

3.2. Perturb & observation algorithm (P&O)

P&O method is a popular MPPT (Maximum Power Point Tracking) direct algorithm because it is simple and easy manner of implementation. DC voltage, duty cycle and shaft speed are acting as the variable control input to the MPPT P&O algorithm. P&O or Hill climbing algorithms needs perturbation in operating voltage and duty cycle of the power converter. MPPT method with boost converter gets higher power from the source. In selecting the step size of the perturbation, because the largest step size leads to an oscillation near by the MPP peak and wastage of energy is increased. On the other hand, smaller perturbation size and creates the slow response under rapid change in input irradiation or change in load.

3.3. Fuzzy logic control

The usage of the FLC deals with the inputs; it does not require an exact mathematical design and it can manage nonlinearity. The FLC contains three phases: fuzzification, inference system and defuzzification. Fuzzification is the process of converting numerical crisp inputs to linguistic variables on degree of membership basis to particular sets. The total functions of membership depend on precision of the controller. In Fig.4 There are five levels of fuzzy here: Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS) and Positive Big (PB).

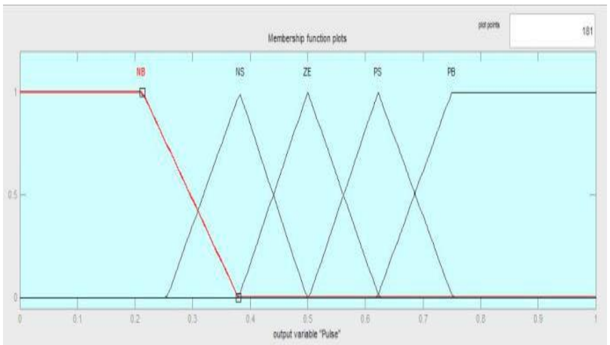


Fig. 4: Membership Function.

In fuzzy controller the input error is E, and the change in error is ΔE. The designer can choose the error, but commonly it is done as $\Delta P/\Delta V$ because it will be noted as zero at MPP. Then E and ΔE are explained below:

$$E = \frac{P(k)-P(k-1)}{V(k)-V(k-1)} \tag{9}$$

$$\Delta E = E(k) - E(k-1) \tag{10}$$

The FLC output is an alteration in the duty ratio of the power converter ΔD, or a change in the reference voltage of the DC-linkΔV. The rule base which is also called as rule base lookup table or otherwise fuzzy rule algorithm which is associated with the fuzzy output to the inputs based on the power converter used. Table. 1 shows the set of rules used for modeling FLC, where the inputs are E andΔE, as defined in (9) and (10), and the output is a change in the DC-link voltage, ΔV.

Table.1: Rule Base

E\CE	NB	NS	ZE	PS	PE
NB	ZE	PB	ZE	NB	NS
NS	PS	ZE	ZE	NB	NS
ZE	ZE	ZE	ZE	ZE	ZE
PE	PS	PB	ZE	ZE	NS
PE	PS	PB	ZE	NB	ZE

The final phase of the FLC is defuzzification. In this phase the output is changed from a linguistic variable to a numerical crisp once again by the usage of membership functions as given in Fig. 4. The merits of these controllers are it deals with uncertain inputs, does not require an exact mathematical structure and managing nonlinearity, quick convergence and fewer oscillations in MPP.

3.4. Cuckoo search optimization

For the usage of MPPT on CS basis, optimum variables have to be choosed as they are explained as the values of voltages, i.e. Vi (i = 1, 2... .n). n is the number of total samples, α is denoted as step size.
The flowchart of the suggested method is given in Fig. 5. Initially, all constants and variables such as voltage, current, power, amount of samples and the value of b is initialized. Using the present current and voltage, the power is calculated. The latest power and voltage are stored in some voltage arrays and fitness arrays, respectively. Furthermore, before the start of every iteration, a check is performed to determine if the samples have already achieved convergence or otherwise. If they come closer to MPP, they will join as an equal value and it will alter the respective power. If the samples do not converge, all the power values of the corresponding samples are measured and are stored in the fitness array. By evaluating the array, the sample with highest power is chosen as the best sample. Thereafter all other samples are forced to go towards this best value.

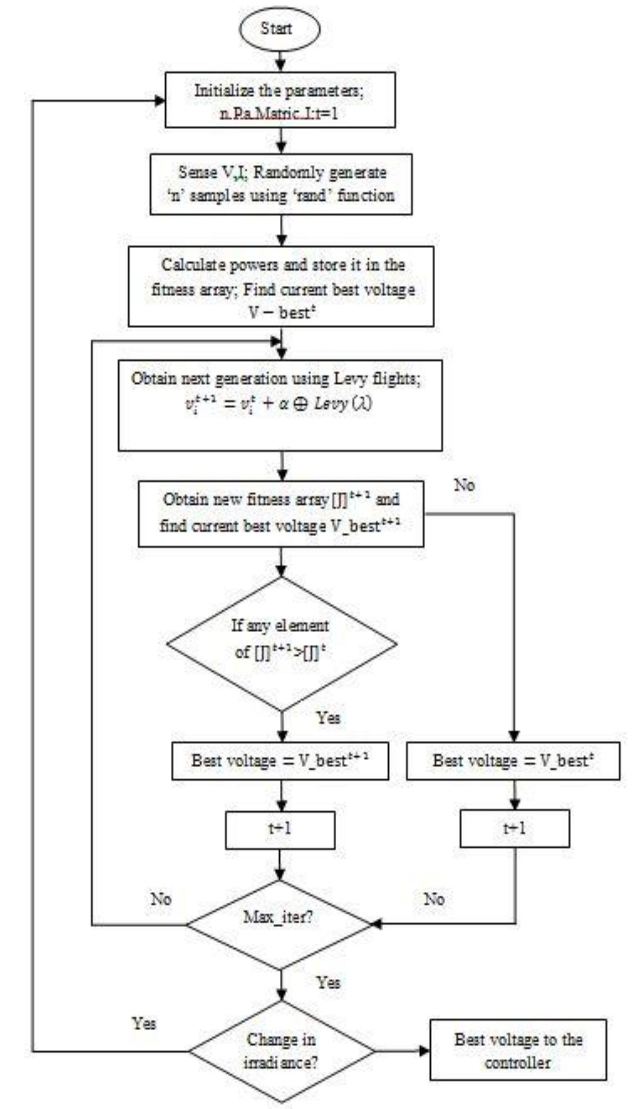


Fig.5: Flowchart of Cuckoo Search Algorithm.

The sizes of step are founded by doing the Levy flight as explained by the equations (11) and (12). On continuation, a latest set of models are found. After this the respective powers of these latest models are calculated from the panel of PV. In other way, if any samples results in a lesser power, then that particular model is removed and a new model is produced. This process will goes on till all the models come closer to the exact point, i.e. MPP.

4. Simulation results and discussion

The simulation results of output voltage comparison of MPPT controllers shown in Fig. 6. The performance of each MPPT controller power output is compared as shown in Fig. 7. The simulation for CSA based MPPT method is carried out the high output voltage and power when compared to other controllers. The performance comparison of PI, P&O, FLC and cuckoo search optimization based MPPT controllers is shown in Table. 2. The cuckoo search optimization has the high power out when compared with the PI, P&O and Fuzzy controllers.

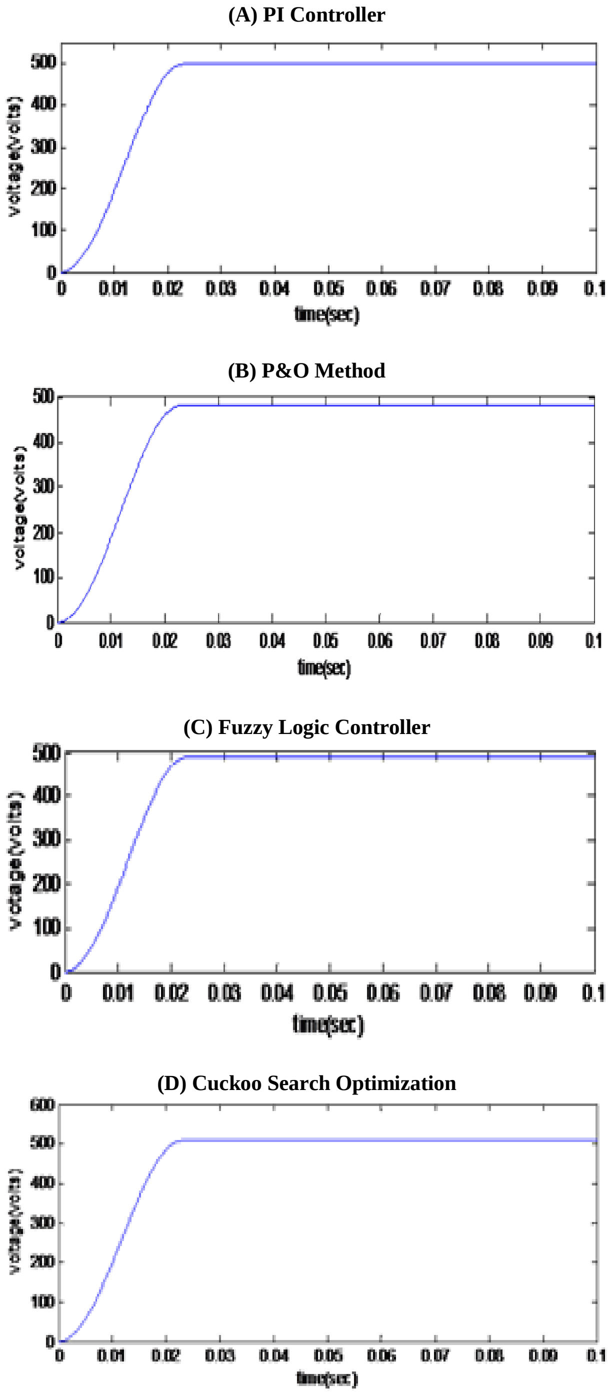
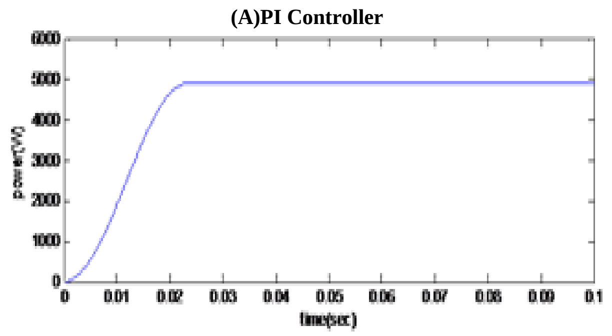
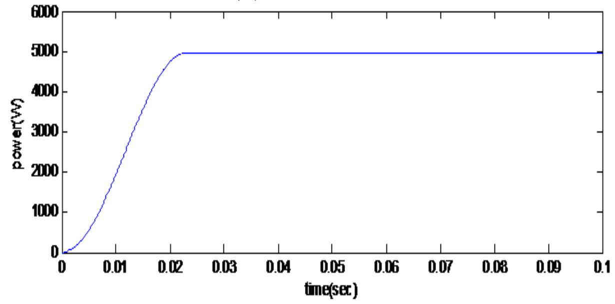


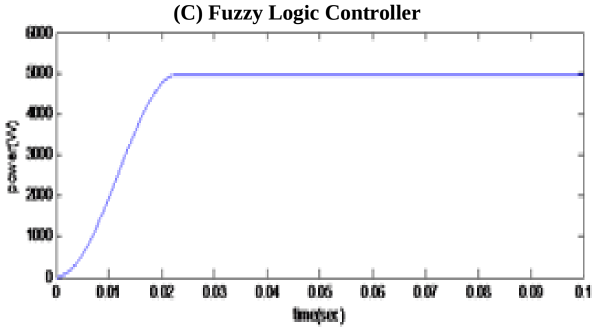
Fig. 6: Output Voltage Comparison of MPPT Techniques.



(B) P&O Method



(C) Fuzzy Logic Controller



(D) Cuckoo Search Optimization

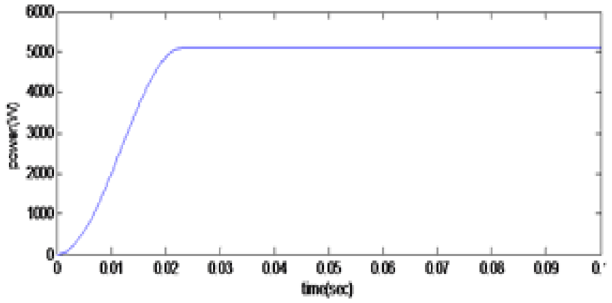


Fig. 7: Power Obtained by Different MPPT Techniques.

The output voltage of cuckoo search optimization is equal to the reference DC voltage estimated to be the DC bus voltage of 510V. Whereas the PI, P&O and fuzzy controllers have an output voltage of 491V, 494V and 500V respectively.

Table 2: Output of Various MPPT Techniques

Parameters	PI	P&O	FLC	Cuckoo Search
Power	4992 W	5093W	5112W	5120W
Voltage	491 V	494V	500V	510V

Specifications of time domain includes rise time, settling time, Peak overshoot and steady-state error is obtained for PI controller, intelligent controllers and optimization methods and the solutions are tabled in Table. 3

Table.3: Comparative Analysis for Time Domain Specifications and Performance Criteria

TYPE	PI	P&O	FLC	Cuckoo Search
Rise time, t_r(sec)	0.33	0.22	0.21	0.078
Settling time, t_s(sec)	0.98	0.7	0.6	0.2
Peak Overshoot (%)	-	-	-	-
Steady-state error, $e_{ss\,(\%)}$	1.2	0.9	0.5	0.3

From the comparative analysis, it is inferred that better voltage control is achieved with minimum rise time of 0.078sec, settling time of 0.2sec, steady state error of 0.3 and no peak overshoot for cuckoo search optimization. From the analysis it can be stated that the cuckoo search optimization based MPPT technique is most efficient maximum power tracking power when compared with PI, P&O and fuzzy based technique. Performance indices such as ISE, IAE and ITAE are tabulated in Table. 4. From the table ISE, IAE and ITAE are very much reduced in Cuckoo Search than all other controller techniques.

Table 4: Comparative Analysis of Performance Indices

Type of Error	PI	P&O	FLC	Cuckoo Search
ISE	0.09919	0.06774	0.0643	0.06017
IAE	862.8	547.1	546.8	212.9
ITAE	1726	1094	1088	425.7

5. Conclusion

In this paper, three MPPT controllers like PI, P&O and FLC controller are designed and the output is matched with wind energy in different condition of wind speed. The performance of each controller is analyzed and it is verified that CSA based controller is more efficient and reliable than PI, P&O and FLC controller. The PI controller failed in tracking the non-linearity of speed of wind by giving less output power. The P&O based technique is suitable for the condition where the system is stable of with minimum variance. The FLC method has a rapid tracking ability. But it takes more time to train the algorithms, because of their mathematical complexity. CSA is quick and efficient method to find the higher power point in WECS. The results obtained from CSA are more efficient, high performing, reducing the time domain, minimizing the performance indices and provides good voltage regulation and power.

References

[1] Vijay Chand Ganti, Bhim Singh, Shiv Kumar Aggarwal, and Tara Chandra Kandpal (2012). "DFIG-Based Wind Power Conversion with Grid Power Leveling for Reduced Gusts", IEEE Transactions on Sustainable Energy, Vol. 3(1), pp.12-20.https://doi.org/10.1109/TSTE.2011.2170862.

[2] M. Matteo, M. Riccardo, D. Vincenzo, and A. Riccardo (2017). "A new model for environmental and economic evaluation of renewable energy systems: The case of wind turbines", Applied Energy, Vol. 189, pp.739-752.https://doi.org/10.1016/j.apenergy.2016.11.124.

[3] B Yang, XS Zhang, T Yu, HC Shu, and ZH Fang (2017). "Grouped grey wolf optimizer for maximum power point tracking of doubly-fed induction generator based wind turbine", Energy Conversion and Management, Vol.133, pp. 427–443.https://doi.org/10.1016/j.enconman.2016.10.062.

[4] N. Delgarm, B. Sajadi, F. Kowsary, and Delgarm S (2016). "Multi-objective optimization of the building energy performance: a simulation-based approach by means of particle swarm optimization (PSO)", Applied Energy, Vol. 170, pp.293–303.https://doi.org/10.1016/j.apenergy.2016.02.141.

[5] M. Wieczorek, and M. Lewandowski (2017). "A mathematical representation of an energy management strategy for hybrid energy storage system in electric vehicle and real time optimization using a genetic algorithm", Applied Energy, Vol. 192, pp.222–233.https://doi.org/10.1016/j.apenergy.2017.02.022.

[6] L. Wei (1998). "Design of a hybrid fuzzy logic proportional plus conventional integral derivative controller". IEEE Transactions on Fuzzy Systems, Vol. 6(4), pp.449–463.https://doi.org/10.1109/91.728430.

[7] T.M. Jabban, M.A. Alali, A.Z. Mansoor, and A.N. Hamoodi (2012). "Enhancing the step response curve for rectifier current of HVDC system based on artificial neural network controller", Journal of King Saud University-Engineering Science, Vol. 24(2), pp.181-192.https://doi.org/10.1016/j.jksues.2012.01.002.

[8] X Zhang, Q Li, M Yin, X Ye, and Y Zou (2012). "An improved hill-climbing searching method based on halt mechanism", ZhongguoDianjiGongchengXuebao, Proceedings of the CSEE, Vol. 32 (14), pp.128–134.

[9] A.O. Deepa, R. Lal Raja Singh and R. Leena Rose (2016). "A novel energy management system using renewable distribution generation units", Journal of Electrical Engineering and Science, Vol. 2(2), pp.1-11.https://doi.org/10.18831/djeee.org/2016021001.

[10] ZM Dalala, ZU Zahid, W Yu, Y Cho, and JS Lai (2013). "Design and analysis of an MPPT technique for small-scale wind energy conversion systems", IEEE Transaction on Energy Conversion, Vol. 28(3), pp.756-767.https://doi.org/10.1109/TEC.2013.2259627.

[11] SMR Kazmi, H Goto, HJ Guo, and O Ichinokura (2011). "A novel algorithm for fast and efficient speed-sensorless maximum power point tracking in wind energy conversion systems", IEEE Transaction on Industrial Electronics, Vol. 58(1), pp.29–36.https://doi.org/10.1109/TIE.2010.2044732.

[12] Z Zhang Z, Y Zhao, W Qiao, and LY Qu (2014), "A space-vector modulated sensorless direct-torque control for direct-drive PMSG wind turbines". IEEE Transactions on Industry Applications, Vol. 50(4), pp. 2331–2341.https://doi.org/10.1109/TIA.2013.2296618.

[13] HM Nguyen and D.S. Naidu (2012). "Direct fuzzy adaptive control for standalone wind energy conversion systems", In: Proceedings of the world congress on engineering and computer science, Vol. 2, pp. 994-999.

[14] MA Mayosky, and GIE Cancelo (1999). "Direct adaptive control of wind energy conversion systems using Gaussian networks", IEEE Transaction on Neural Network, Vol. 10(4).https://doi.org/10.1109/72.774245.

[15] SangitaRoy, and SheliSinhaChaudhuri (2013). "Cuckoo Search Algorithm using Levy Flight: A Review", International Journal of Modern Education and Computer Science, pp: 10-15.https://doi.org/10.5815/ijmecs.2013.12.02.

[16] M. Mary Linda, and M. AnjanaRency (2015). "DC-DC converter control unit for variable speed wind turbine", Journal of Electrical Engineering and Science, Vol. 1(1), pp. 43-52.https://doi.org/10.18831/djeee.org/2015011005.