A Technical Survey on Controllers of Wind Energy Conversion System

Naresh Kumar Yadav
Electrical Engineering Department
Deenbandhu Chhotu Ram University of Science & Technology
Murthal (Sonepat)

***Abstract*—Due to rising demand renewable energy method is receiving more attention as well as threat zero carbon footprints. As a source of energy, the energy from wind has a great possible. With respect to grid integration, the rising demand of wind energy leads to generate a quality output power. To control the power generation a suitable controller is need by the wind energy. In this paper, numerous amounts of research publications reports are reviewed. Here, WECs is considered as the auspicious renewable energy that obligates researchers to look for effectual control accompanied by minimum cost. From wind, control schemes are receiving better significance in harvesting energy in an efficient manner and they are important in energy conversion procedure. To attain a reliable as well as high-quality power supply, the irregular nature of the wind speed leads a difficult process for the control scheme. Finally, this survey investigates various control methods as well as results of numerous research work that is performed in past in the area of WECs. Research gaps and challenges, as well as the parameters of different control methods, is accurately analyzed as well as examined. This paper leads to explore the new scheme of control approach therefore provided that the competent and recent research development methods to controllability as well as stability of WECS.**

Keywords—Controller; Wind Energy; renewable source; converter; fuzzy; FOPI

Acronym	Description
WECSs	Wind Energy Conversion Systems
PMSGs	Permanent Magnet Synchronous Generators
WES	Wind Energy Source
GHS	Greenhouse Gases
FO-PI	Fractional Order PI Controller
SMSF	Sliding Mode Supervised Fractional order controller
SMS	Sliding Mode Supervisor
MFO	Moth-Flame Optimization
BPCs	Blade Pitch Controllers
PID	Proportional-Integral-Differential
FFOPI+I	fuzzy fractional order PI+I
VS-WECS	Variable Speed WECS
MSC	Machine Side Converter
DFIG	Doubly Fed Induction Generator
FLC	Fuzzy Logic Controller
MPPT	Maximum Power Point Tracking
DC	Direct Current
GSC	Grid Side Converter
RSC	Rotor Side converter
MPPT	Maximum Power Point Tracking
AFGPI	Adaptive Fuzzy Gain Scheduling of Proportional Integral
GA	Genetic Algorithm
HSA	Harmony Search Algorithm
PI	Proportional Integral
MEPT	Maximum Electrical Power Tracker
FF	Firefly
DG	Distributed Generators
VSC	Voltage Source Converter
SVC	Static Var Compensator
IGs	Induction Generators
SA GHSA	Self-Adaptive Global HSA
RBFN	Radial Basis Function Network
SEIG	Self Excited Induction Generator
DG	Distributed Generators
DSP	Digital Signal Processor
INNBC	Intelligent Neural Network Based Control
BESS	Battery Energy Storage System

I. INTRODUCTION

In growth of any country, energy plays a very important role. All over the world, growth in demand for energy depends on sudden increase in population and urbanization. In addition, increase in energy demand suddenly depends on the modernization in the meadow of irrigation as well as agriculture sector. By fossil fuel, the main source of energy is subjugated at present [22]. Many countries discover complexity so as to overcome challenges among demand as well as supply because of the depletion of fossil fuels. The fossil fuel has great pessimistic influence in the environment analysis especially in greenhouse effect, [20]. Based on the factor namely accessible, environmentally friendly as well as affordable, the contemplation of energy depends. From renewable energy sources [18], generation of electricity is referred as an essential and alternative source for the fossil fuel [21].

In recent times, the decrease in natural resources and the high demand of electrical energy led to focus for the novel, pure as well as unlimited sources of energy [19]. Therefore, in the last decades, the renewable energies have gained much interest. Consequently, focusing on the positioned capacity globally, the wind energy is considered as the developed sources that are about 485 GW 12.63 GW for Europe. In fact, in modern WECSs, the PMSGs have received much interest due to the high torque to current ratio, variable speed operation, minimum converter cost, fast dynamical response, , minimized power losses brushless system with high reliability as well as minimum noise. Nevertheless, the nonlinearity, variable load torque as well as physical parameters, are considered in the design of PMSG as significant problems.

In future, WES is considered as well-known electrical energy sources[16]. WES doesn't have effects on renewable source such as the GHG emissions as well as climate issues. The rising interest in environmental issues demand green, renewable, as well as sustainable concepts. For this dilemma, fuel cells, and wind turbines with solar energy are probable inventive results. WES is considered as a non-polluting and depleting, site-dependent, as well as a possible alternative energy source [22]. In many countries, already wind energy has achieved diffusion level that araises few technical issues about grid integration. WE have to overcome few economic and technical barriers if it ought to create a considerable part of electricity [17].

When enhancing the power quality, principal objective of the control scheme needs to provide economical and reliable power in the power system. The WECS is not only exploited for producing electricity from the wind. However it is about utilizing energy competently [24]. On the other hand, to indicate WTGs spatial distribution and to build a detailed time-domain model, as well as the ground environment of the wind farm is a difficult process. In addition, to attain precisely and comprehensively parameters are difficult due to the great number of parameters need. The comprehensive model is difficult even if all the required parameters are attained. Hence, the wind energy conversion procedure is practical and possible for structuring an equivalent framework [25]. An equivalent power curve of the wind farm is a commonly exploited time-domain equivalent framework among conventional equivalent frameworks for transmuting predicted wind speed into electric power. For attaining the power curve in the field measurements, IEC 61400-12-1 presents a process. The wind speed data with the average of 10-min are commonly utilized as well as a extensive term data collection is needed. For a wind farm, while the equivalent power curve is utilized, this is unable to exploit in time intervals of seconds. The equivalent modeling with the time domain will be considerably more complex in small time scales.

The main contribution of this paper is to review on state-of-the arts of controllers of WECs. The organization of the paper is represented as follows: Section II narrates the literature review; Section III reports the review on Controllers of WECs. Section IV portrays the research gaps and challenges. Section V concludes the paper.

II. Literature Review

In 2018, Yuqing Jin *et al.* [1] studied the relation among whole effect of spatial as well as all the pitch angle controllers of the wind farm. For the frequency domain equivalent modeling approach, they have developed a theoretical derivation. To attain equivalent model, the proposed modeling approach was the easiest process for the whole wind energy conversion procedure for wind farm. Before invading to wind farm, speed of wind was considered as the solely input signal for proposed equivalent model. This was termed as original incoming wind speed. Moreover, in the proposed model, a discrete transfer function was attained for all the spatial effects in a wind farm as well as wind energy conversion procedure. Finally, a compensation power with negative value was attained utilizing the compensation of the wind speed.

In 2018, Hamza Afghoul *et al.* [2] worked on to construct an appropriate controller to attain the utmost wind turbine power point for speed control loop in severe circumstances. In addition, to meet load variations in a high range and also to guarantee the outer voltage stability regulation loops. In order to resolve the disadvantages of the existing ones, the intelligent controllers were exploited in recent times. However, they insist on high-speed calculators as well as expensive cost. By expanding integration order from the order of integer to real, many solutions proposed FO-PI. The FO-PI controller occurs some weakness in steady state, which occurred by the approximation approaches. The main initiative of this paper was to present a SMSF that comprises of existing PI controller. One of the controllers to guarantee fine steady as well as transient states, the FO-PI controller and SMS was exploited.

In 2018, M.A. Ebrahima, *et al.* [3] exploited MFO approach to present a new algorithm for distributed optimization as well as control. Here, for WECS the MFO-based design of BPCs was proposed to improve damping oscillations for the voltage and output power. To understand benefit of the proposed hybrid approach, uncomplicated PID was exploited. To achieve this study, Single wind turbine system, supplied in BPC-PID (MFO), was contemplated. The recommended WECS method comprises small and large-scale uncertainties. A candidate time-domain on the basis of the objective function was reduced, and MFO was exploited so as to search for best controller parameters.

In 2016, Antar Beddar *et al.* [4] presented a FFOPI+I controller for grid-connected VS-WECS. To control a PMSG linked to the nonlinear as well as grid load through a AC-DC-AC PWM converter, the FFOPI+I controller was utilized. At first, the control stratagem of the MSC aspires under fluctuating wind speed to extort a maximum power. Subsequently, to improve the power quality, the GSC was controlled and guarantees sinusoidal current in grid side. By having a commune proportional gain, FFOPI+I controller implements a FLC in parallel with FOPI and existing PI controllers.

In 2016, Mazhar H. Baloch *et al.* [5] developed a nonlinear controller design method as well as the system modeling of wind turbine induction generator unit. It was on the basis of the feedback linearization, and field oriented control method. To stabilize wind turbine system parameters, the nonlinear controller parameters was synthesis with the cage generator and wind turbines that were untrustworthy regarding arbitrary wind speed by linearization appearance. It was suitable for the applications of wind turbine system and proposed topology idea was a least cost. The significant parameters, which must be adjusted, were the frequency of the perturbation signal and probing voltage amplitude.

In 2016, Ramji Tiwari and N.RameshBabu [6] worked on Renewable energy approach, which gained more attention because of rising demand as well as threat zero carbon footprints. As energy source, energy from wind has a high possible. The rising growth of wind energy is inclined to create a output power quality regarding integration grid. By the wind energy to control the power produce a suitable controller was needed. A numerous amount of research publications reports had analyzed on MPPT, GSC and MSC linked with WECS. Nevertheless, survey on pitch angle based control was not concentrated completely in such reviews. Here, power extraction control as well as grid synchronization control was analyzed, a brief review of pitch angle controller.

In 2016, Ahmed Medjber *et al.* [7] presented a novel control scheme to guarantee high power point tracking of DFIG based WECS. Among the machine and the grid, the power transfer was controlled; the proposed scheme exploits fuzzy logic controllers as well as neural networks, and it was used to indirect vector control and reactive power control methods. Utilizing dual identical converters, this transfer was guaranteed by controlling the rotor. To the RSC, the first converter was associated and to the GSC the second converter was associated using filter. By a fuzzy controller, the DC link voltage was controlled. By limiting the voltage or output current, this control scheme was exploited in order to guard and control the rotor side currents as well as the generator.

In 2016, Hassan Fathabadi [8], proposed a new high precise sensorless MPPT technique. The approach follows the real maximum power point of a WECS in that utmost output power was derived from the system. Nevertheless, utmost power point of its wind turbine was not attained in utmost mechanical power from the turbine. As a result, maximum output power actually extracts from the system. Proposed method solely utilizes current as well as input voltage of the converter exploited in the system. By constructing a WECS the approach was designed as a controller of MPPT. By presenting real experimental outcomes, method performance, as well as its benefits were examined.

In 2018, Nektarios E *et al.* [9] presented a maximum competence control scheme for a WECS in DFIG. For MPPT as well as DFIG, the proposed control strategies offer loss of power minimization of wind turbine. So, from similar wind energy augmented electric energy production possible was obtained. Thus, cut-in wind speed was minimized and, expansion of exploitable wind speed area was attained. In DFIG the high effectiveness was obtained by the stator frequency. Through controlling the turbine speed in proper manner and the maximum harvesting, magnetic-flux in the turbine was attained. As controller parameters were examined experimentally proposed control system was simply implemented. Therefore, the proficiency of the wind system framework was not needed. In addition, a converter system of minimum power needs was exploited for validation of the proposed control strategies. Therefore, this benefit of the WECS in DFIG over other electrical generator kinds was still accurate.

In 2015, K. Bedouda *et al.* [10] developed the WECS based on DFIG model. Initially, the vector control scheme of the active and reactive powers was considered to guarantee a best operation. The complete system was developed in d-q-synchronous reference framework. Subsequent to the design of AFGPI Controller for WECS was explained, whereas the optimization by Fuzzy rules was exploited online on the basis of error and its first derivative to adjust the parameters of PI controller. At last, the control of the reactive as well as active power employing fuzzy-PI controller was validated. Performance and robustness outcomes attained were presented and analyzed.

In 2018, Mohammadreza Toulabi *et al.* [11] presented a proportional-derivative frequency controller as well as examine its performance analysis in wind farm, which consist of various VSWTs. Before the proposed controller, a band-pass filter was deployed to shun react to the deviation of steady state frequency. First, the frequency framework of the wind farm was represent to design the controller. On the basis of the attained open loop system, the proposed controller was designed. The closed-loop system's was decomposed and the characteristic polynomial was added into the odd and even parts, the stability area related with the parameters controller was systematically validated. At last, best values related with the parameters controller were validated on the basis of attained possible area and suitable objective function, utilizing the GA.

In 2015, C. Viveiros *et al.* [12], worked on a hierarchical structure collected and dual distinct PI controllers in a bottom level and an event-based supervisor in a upper level. Wind energy conversion system with DFIG to a variable speed, the controllers was applied, such as the fuzzy PI control as well as FOPI control. On the basis of four probable operational conditions such as park, the event-based supervisor analyses generating start-up, or brake and sends, the operation state of the wind energy conversion system. The controllers only operate on electric torque in start-up state though pitch angle was equal to zero. The controllers have to placed on the pitch angle of the blades in generating state to preserve the electric power around the nominal value. Thus assures that the safety circumstances necessary for integration in the electric grid were met.

In 2017, Hassan Fathabadi [13] introduced the design of a MEPT, and reveals that MEPT removes utmost output electrical power from WECS while a MPPT only removes maximal mechanical power from wind turbine. The idea of a MEPT introduces the novelties and contributions of the work and presents two new MEPT and MMPT methods, which have higher MPPT effectiveness as well as minimum convergence times while compared with existing methods. The other benefits of using the proposed MEPT and MMPT are simple structure, low-cost, and good response to sudden variations in wind speed. In addition, to validate theoretical outcomes the experimental and simulation verifications were presented.

In 2017, Hossam Keshta [14] studied the stability and performance of the WECS on the basis of the SVC. The incorporation of wind farm on the basis of the IGs in a network without reactive power compensation, which led to the voltage collapse in the system, therefore it turns out to be unstable. The study reveals that at the point of general coupling a dynamic reactive power compensation SVC was successful so the system stability increases. This study presents exploiting advanced optimization methods on the basis of the artificial intelligence namely HSA, SA GHSA, FF method.

In 2017, Damodhar Reddy and Sudha Ramasamy [15], presented a RBFN controller-bon the basis of the three-phase boost-type Vienna rectifier for a grid-tied wind energy conversion system. For Vienna rectifier, this paper engages the validation of an RBFN on the basis of the control scheme to attain improved performance of a wind energy conversion system and to determine the capability of the proposed scheme. For the control of the rectifier system, the option of the RBFN from its inherent capability to guarantee improved dynamic control during the network training phase despite its ability to decrease the design complexities.

In 2017, Saurabh Mani Tripathi [16], attempted to model proportional- PI controllers, it was modeled in order to overwhelm frequently encountered trouble. In WES, the characteristic equations for several control loops were developed, by the D-partition method. In the parametric plane, the frequency scanning check, as well as most stable zones, were identified. PI controller parameters were chosen to guarantee maximum degree of relative system stability as well as good damping ratio, for different sets of controller parameters selected from the identified stable zone by comparing the step responses of the control loop plotted. Under wind speed condition, the WES performance included in designed values of the parameters for PI controllers.

In 2016, Ujjwal Kumar Kalla *et al.* [17], deals with a sone-phase standalone WECS exploiting a two winding SEIG. Proposed controller comprises of a dual leg VSC as well as BESS associated at its DC bus. Exploiting an INNBC algorithm, the VSCBESS system was controlled in a rate of dynamic learning, which depends on the change of load current rate to attain outstanding steady and dynamic state response of the system. In real time, the proposed method was implemented by a DSP. Experimental, simulated steady state as well as proposed SEIG dynamic performances were presented using INNBC algorithm in proposed controller. In all kinds of dynamic loading as well as steady-state circumstances, the frequency, as well as system voltage, were preserved constant.

III. Review on Controllers of WECs

A. Classified techniques in controllers of WECs

Fig 1 demonstrates the classification of different approaches in controllers of WECs. Here, Frequency-domain equivalent model [1], SMSF [2], MFO [3] [4], Squirrel-cage induction generator [5], Pitch angle based control [6], Neural network [7] [14] [17], MPPT [8] [12], High efficiency control strategy [9], AFGPI [10], Hierarchical controller structure [12], RBFN [15], and D-Partition Technique [15] methods are exploited.

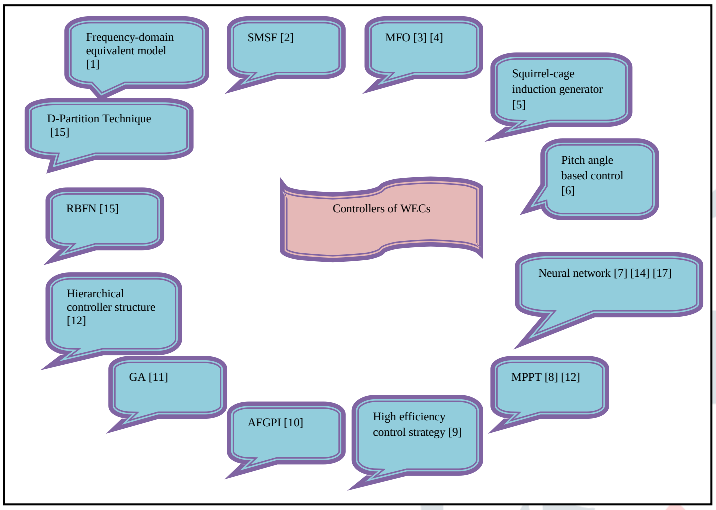

Fig. 1. Classification of Controllers of WECs

B. Survey on different matrices in state-of-the-art of WECS

Survey on different performance metrics in state of the art of WECs is summarized in Table 1. Here, the metrics such as Error indicators, Wind direction, Wind speed, Efficiency, Rotor resistance, Response time and Power factor in WECs are exploited. Among the metrics, the Computation error indicators are exploited by 23.5% of researchers. The wind speed is exploited by the 30% of researchers. The efficiency and rotor resistance is exploited by the 11.7% of researchers. In addition, the response time is exploited by 35% of researchers and the power factor is exploited by 23.5% of researchers. The other metrics are exploited by 73% of researchers.

TABLE I. Performance metrics Comparision for WECs

Citation	Error indicators	Wind direction	Wind speed	Efficiency	Rotor resistance	Response time	Power factor	Others
[1]	√	√						
[2]	√							
[3]							√	√
[4]						√	√	√
[5]			√					
[6]		√				√		√
[7]	√	√				√		
[8]			√	√			√	√
[9]			√					√
[10]							√	√
[11]					√	√		√
[12]			√					√
[13]				√				√
[14]			√			√		
[15]	√					√		
[16]					√			√
[17]								√

C. Performance analysis of different metrics in WECs

The results for the maximum performance analysis value for different metrics in WECs are presented in Table II. Among the performance metrics, the response time is considered as most widely utilized metrics in WECs. The error indicators exploited in [1] which obtained maximum value of 31.97. The Wind direction in [6] attained 298 as maximum value. The Wind speed used in [12] and [14] attained 7. The efficiency in [8] obtained maximum value of 99.28. The rotor resistance used in [11] attained the maximum value of 0.00488. Power Factor in [3] attained 0.5. The other metrics such as Wind turbine response [5], Power quality [6], Delay [9], Stator resistance [11], Rotor resistance [11], Pitch angle [12], Convergence time [13], Grid current loop [16], Load power [17] and Reactive power [17] are exploited in Table II.

TABLE II. MAXIMUM PERFORMANCE FOR DIFFERENT METRICS IN WECS

Citation	Measures	Maximum value
[1]	Error indicators	31.97
[6]	Wind direction	298
[12]	Wind speed	7
[8]	efficiency	99.28
[11]	Rotor resistance	0.00488
[14]	Response time	8
[3]	Voltage deviation	0.1
[8]	Power factor	0.5
[5]	Wind turbine response	12
[6]	Power quality	0.2
[9]	Delay	0.5
[11]	Stator resistance	0.00488
[11]	Rotor resistance	0.00549
[12]	Pitch angle	36
[13]	Convergence time	15
[16]	Grid current loop	70.69
[17]	Load power	2.94
[17]	Reactive power	2.22

D. Performance analysis of wind power in state-of-art

Table III summarizes the performance analysis of wind power in state of the art of WECs. Here, [1] achieves maximum performance of 31.97, [5] achieves maximum performance of 7, [7] achieves maximum performance of 6.5, [8] achieves maximum performance of 10, [9] achieves maximum performance of 3.5, [12] achieves maximum performance of 22.5, [14] achieves maximum performance of 30, and [15] achieves maximum performance of 11 with respect to the wind power.

Citation	Maximum value (MW)
[1]	31.97
[5]	7
[7]	6.5
[8]	10
[9]	3.5
[12]	22.5
[14]	30
[15]	11

IV. RESEARCH GAPS AND CHALLENGES

The reduction of conservative energy sources for instance gas and oil, as well as the need to restrict their utilize because of the environmental unease, has led to the search to meet the ever-growing demand of electrical power for augmented use of renewable energy sources. On various kinds of available renewable energy sources, wind is considered as one of the promising energy source. Substantial research is performed during the last decade to enhance wind turbine design as well as control for augmented power conversion effectiveness and ease of use. In recent times, because of the perceived economic as well as technical advantages the deregulated electricity market is opened the doors for customers owned DG. At distribution voltage levels, the DGs are usually connected to the system. Based on the individual requirements of the customers, reliability levels and customized power quality is attained utilizing power electronic on the basis of the power processing units. On a variety of operating conditions, the diversified nature of the power system collectively be capable of the result in a power system capable of presenting the preferred level of service with the exploit of power electronics based power processing units. In the off-grid operating mode, the control of a system with restricted energy capabilities exploiting existing control techniques, which is widely employed in power systems is a complex task. If the system comprises a renewable energy source namely wind energy power conversion unit, the circumstances become even more multifaceted because this type of most important energy source is frequently intermittent in availability. A storage device in the system becomes essential to comprise a dispatchable energy source. A radically different method is needed for the control design of such a system while operation of these systems in operating conditions against a wide range is need to weather changes. During the two operating modes, the operating conditions can comprise off grid and on-grid mode of operation and changes in the amalgamation of the internal energy sources, which supplies the load. The power electronic converters have the benefit in terms of connecting the wind energy conversion units to the efficacy system that the units is operated at variable speeds to maximize energy capture from the current wind circumstances and to ease stresses in the drive train. On the utility side, the converter interface to the effectiveness also shields these units from normal disturbances and offers the capability to transfer the wind-generated power to the efficacy side with enhanced quality of the power. On the other hand, existing control strategies employed for the interfacing power electronic converters do not offer suitable operation on the utility systems. During temporary faults can take out of service during faults because of the operation for the switch overload protection. On the utility system, the most of faults are provisional single line to ground faults, and these can give significantly to the downtime of these wind conversion systems.

V. CONCLUSION

Wind was exploited as a power source for several years. Production of electrical energy from wind was received a notable step in the last decade due to the existing resources and maximizing environmental problems. Recently, apprehension has developed towards sources of renewable energy mainly wind energy for the generation of electricity. To search the solution for productive use of wind energy the researchers as well as scientist have gone through exact study and experimentation. Our everyday activities was heavily depends on energy therefore the work towards energy research was highly significant and sensitive. Consequently of wide research, wind energy was extensively exploited for electrical power generation. This paper makes an effort to show a short survey of WECs, which highlights different control strategies. The vital survey findings, enduring research as well as future probable enhancements for WECs were discussed in this paper. In addition, this paper reviews the modeling of WECS, control strategies of controllers and several technologies, which were proposed for effectual production of wind energy from the available resource.

References

[1] Yuqing Jin, Ping Ju, Christian Rehtanz, Feng Wu, Xueping Pan,"Equivalent modeling of wind energy conversion considering overall effect of pitch angle controllers in wind farm" Applied Energy, vol. 222, pp. 485-496, 15 July 2018.

[2] Hamza Afghoul, Fateh Krim, Badreddine Babes, Antar Beddar, Abbas Kihel,"Design and real time implementation of sliding mode supervised fractional controller for wind energy conversion system under sever

working conditions",Energy Conversion and Management, vol. 167, pp. 91-101, 1 July 2018.

[3] M. A. Ebrahim, M. Becherif, Almoataz Y. Abdelaziz,"Dynamic performance enhancement for wind energy conversion system using Moth-Flame Optimization based blade pitch controller", Sustainable Energy Technologies and Assessments, Volume 27, pp. 206-212, June 2018.

[4] Antar Beddar, Hacene Bouzekri, Badreddine Babes, Hamza Afghoul,"Experimental enhancement of fuzzy fractional order PI+I controller of grid connected variable speed wind energy conversion system", Energy Conversion and Management, vol. 123, 1 , pp. 569-580, September 2016.

[5] Mazhar H. Baloch, Jie Wang, Ghulam S. Kaloi,"Stability and nonlinear controller analysis of wind energy conversion system with random wind speed", International Journal of Electrical Power & Energy Systems, vol. 79, pp. 75-83, July 2016.

[6] Ramji Tiwari, N. Ramesh Babu,"Recent developments of control strategies for wind energy conversion system", Renewable and Sustainable Energy Reviews, vol. 66,, Pages 268-285, December 2016.

[7] Ahmed Medjber, Abderrezak Guessoum, Hocine Belmili, Adel Mellit,"New neural network and fuzzy logic controllers to monitor maximum power for wind energy conversion system", Energy, vol. 106, pp. 137-146, 1 July 2016.

[8] Hassan Fathabadi,"Novel high efficient speed sensorless controller for maximum power extraction from wind energy conversion systems", Energy Conversion and Management, vol. 123, pp. 392-401, 1 September 2016.

[9] Nektarios E. Karakasis, Christos A. Mademlis, "High efficiency control strategy in a wind energy conversion system with doubly fed induction generator", Renewable Energy, vol.125, pp. 974-984, September 2018.

[10] Khouloud Bedoud, Mahieddine Ali-rachedi, Tahar Bahi, Rabah Lakel,"Adaptive Fuzzy Gain Scheduling of PI Controller for Control of the Wind Energy Conversion Systems", Energy Procedia, vol. 74, pp. 211-225, August 2015.

[11] Mohammadreza Toulabi, Shahab Bahrami, Ali Mohammad Ranjbar,"Optimal supplementary frequency controller design using the wind farm frequency model and controller parameters stability region", ISA Transactions, vol. 74, pp. 175-184, March 2018.

[12] C. Viveiros, R. Melício, J. Igreja, V. M. F. Mendes,"Performance assessment of a wind energy conversion system using a hierarchical controller structure", Energy Conversion and Management, vol. 93, pp. 40-48, 15 March 2015.

[13] C. T. Pan and Y. L. Juan, "A Novel Sensorless MPPT Controller for a High-Efficiency Microscale Wind Power Generation System," IEEE Transactions on Energy Conversion, vol. 25, no. 1, pp. 207-216, March 2010.

[14] H. Keshta, A. Ali, E. Saied and F. Bendary, "Comparative performance of wind energy conversion system (WECS) with PI controller using heuristic optimisation algorithms," in CIRED - Open Access Proceedings Journal, vol. 2017, no. 1, pp. 549-553, 10 2017.

[15] D. Reddy and S. Ramasamy, "Design of RBFN Controller Based Boost Type Vienna Rectifier for Grid-Tied Wind Energy Conversion System," IEEE Access, vol. 6, pp. 3167-3175, 2018.

[16] S. M. Tripathi, A. N. Tiwari and D. Singh, "Controller Design for a Variable-Speed Direct-Drive Permanent Magnet Synchronous Generator-Based Grid-Interfaced Wind Energy Conversion System Using D-Partition Technique," IEEE Access, vol. 5, pp. 27297-27310, 2017.

[17] U. K. Kalla, B. Singh and S. S. Murthy, "Intelligent Neural Network-Based Controller for Single-Phase Wind Energy Conversion System Using Two Winding Self-Excited Induction Generator," IEEE Transactions on Industrial Informatics, vol. 12, no. 6, pp. 1986-1997, Dec. 2016.

[18] D. L. Hau Aik and G. Andersson, "Impact of renewable energy sources on steady-state stability of weak AC/DC systems," CSEE Journal of Power and Energy Systems, vol. 3, no. 4, pp. 419-430, Dec. 2017.

[19] A. M. Leite da Silva, J. F. d. Costa Castro and R. Billinton, "Probabilistic Assessment of Spinning Reserve via Cross-Entropy Method Considering Renewable Sources and Transmission Restrictions," IEEE Transactions on Power Systems, vol. 33, no. 4, pp. 4574-4582, July 2018.

[20] A. M. Leite da Silva, J. F. d. Costa Castro and R. Billinton, "Probabilistic Assessment of Spinning Reserve via Cross-Entropy Method Considering Renewable Sources and Transmission Restrictions," IEEE Transactions on Power Systems, vol. 33, no. 4, pp. 4574-4582, July 2018.

[21] J. Ou, X. Liu, X. Li and X. Shi, "Mapping Global Fossil Fuel Combustion CO2 Emissions at High Resolution by Integrating Nightlight, Population Density, and Traffic Network Data," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 9, no. 4, pp. 1674-1684, April 2016.

[22] H. Rudnick, R. Palma-Behnke, A. Rudnick and C. Benavides, "Restless Waters: Fossil Fuel Emissions Conditioning a Reduction in Hydroelectric Resources in Chile," IEEE Power and Energy Magazine, vol. 12, no. 5, pp. 50-60, Sept.-Oct. 2014.

[23] J. Mohammadi, S. Vaez-Zadeh, E. Ebrahimzadeh and F. Blaabjerg, "Combined control method for grid-side converter of doubly fed induction generator-based wind energy conversion systems," IET Renewable Power Generation, vol. 12, no. 8, pp. 943-952, 6 11 2018.

[24] K. A. Chinmaya and G. K. Singh, "Performance evaluation of multiphase induction generator in stand-alone and grid-connected wind energy conversion system," IET Renewable Power Generation, vol. 12, no. 7, pp. 823-831, 5 21 2018.

[25] M. I. Mosaad, "Model reference adaptive control of STATCOM for grid integration of wind energy systems," IET Electric Power Applications, vol. 12, no. 5, pp. 605-613, 5 2018.