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Controller for Wind Energy Conversion System using Whale Optimization Algorithm

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Abstract **The direct drive permanent magnet synchronous generator (PMSG) have many advantages consequently, it ends up a standout amongst the most appealing variable speed wind generation types. This paper proposes a novel application of a Whale Optimization Algorithm (WOA) aims at finding the optimal parameters of the conventional Proportional-Integral (PI) controllers for the DFIG based wind energy conversion system (WECS). The Whale Optimization Algorithm (WOA) is applied to the classical PI-controller on machine side converter system to find the optimal gains of the PMSG, to such an extent that a maximum power point tracking (MPPT) under normal condition, a step change of wind speed and the optimal dynamic performance of DFIG under grid fault can be easily achieved. Three case studies in this paper, dynamic responses of the system under normal operation, a step change of wind and a three-phase symmetrical fault with using crowbar protection and without crowbar protection. The optimal values that result from the WOA algorithm are compared with the simplex method.**

Keywords— WOA,DFIG,WECS,MPPT

I. INTRODUCTION

In India, electricity generation fuels use conventional energy sources such as coal, gas, and oil, which are limited availability increasingly depleted. In addition, the use of conventional energy sources in power plants produces carbon dioxide emissions of 500g CO2 / kWh up to l200g CO2 / kWh . Therefore renewable energy sources have been developed as a substitute for conventional sources. At present, the wind energy conversion system is developing rapidly as an electric energy generator due to its unlimited availability, carbon dioxide emissions-free, and environmentally friendly. In practice, WECS with a variable speed wind turbine (VSWT) is more widely used because it is more effective and can optimize wind energy conversion . VSWT is designed for a wide wind speed range to get maximum aerodynamic efficiency so that increases captured energy, increases power quality and reduces mechanical losses in wind turbines . WECS is very influenced by the varying wind speed so that the output power will fluctuate as well. At wind speeds below nominal value, the main purpose of the controller in a wind turbine system is to optimize the captured energy so that it gets the maximum output power . To increase the output power and efficiency, the WECS must operate at the maximum power point so that a power extraction is needed to get maximum power at each wind speed. Several methods have been designed to extract maximum power in wind turbine systems. The tip speed ratio (TSR) method is a simple method for extracting maximum power but requires measurement of wind speed . The optimal torque control method (OTC) is simpler and faster than TSR method because it does not require wind speed measurement but requires the characteristics of a wind turbine. A mechanical sensor is required on TSR and OTC methods in the form of anemometer and tachometer for measurement of wind speed and rotor speed so that reducing accuracy and increasing system costs Perturb and Observe (P&O) methods can extract maximum power without using mechanical sensors and are easily applied. In the P&O method, perturbation is given by step to change the rotor speed and output power is observed to regulate perturbation and obtain maximum power But this method produces oscillations at the optimum power point and depends on the step size used. Fuzzy logic, neural networks, and intelligent controls have also been applied to power extraction. One of intelligent control method is particle swarm optimization (PSO) which is inspired by the behavior of a group of birds. Several studies have been done to apply PSO to the renewable energy system. The WOA method has been developed as an MPPT for DFIG systems and can determine maximum power points with faster convergent time and better dynamic responses than the P&O methods WOA has also been applied to wind turbine systems using a double-fed induction generator (DFIG) as a controller and produces better performance. loss

II. LITERATURE SURVEY

Johan One of the most important types of renewable energy is wind energy. The electricity produced from wind energy is adequate for its intended end-use and its cost is small compared with other types of renewable energy (Aliyu et al., 2018; Hossain and Ali, 2015). Variable-speed wind turbines (VSWTs) power generation has become more attractive than the fixed speed wind turbines (FSWTs) (Du et al., 2019) because the variable speed operation of VSWTs helps in capturing more power from the wind and reducing the flicker issues (Kadam and Kushare, 2012). VSWTs are made of two generators: doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs) (Tripathi et al., 2015). DFIGs have the advantage of using a partial scale power converter. However, the machine stator in DFIGs is directly connected to the grid which affects the machine performance for any temporary faults or grid disturbances (Kumar and Chatterjee, 2020). Direct-driven PMSGs have become increasingly relevant in recent times because they have high torque to inertia ratio and high-power density. Lack of gearbox and slip rings in PMSGs result in low maintenance and high efficiency at a reduced rotational speed. Also, PMSGs work at fullscale power converters with high grid capability (Aguemon et al., 2020; Mahmoud et al., 2019). In the direct-driven PMSG-based wind turbine (WT), the generator is linked directly to the turbine. The complete back-to-back converter is implemented for it to be able to develop a connection with the utility grid. The machine side converter (MSC) and grid side converter (GSC) use the dominated controllers' field-oriented (FO) controller and a voltage-oriented (VO) controller (Nahome et al., 2011; Ratnam et al., 2020). Maximum power point tracking (MPPT) and fault ride-through (FRT) capability improvement are the main control tasks in wind energy conversion system (WECS) (Meghni et al., 2020; Qais et al., 2020; Ratnam et al., 2020). Till now, the classical proportional–integral (CPI) controller is used in the MSC and GSC of PMSG due to its simple structure and reliability. The main drawback of CPI controller is its weak performance during variable operating conditions such as variable wind speed and fault incidents (Jahanpour-Dehkordi et al., 2019; Shehata, 2017). Nowadays, optimization algorithms are effective in fine-tuning the CPI controller to boost the dynamic behavior of PMSG. Many optimization techniques such as Jaya optimizer (JO), particle swarm optimizer (PSO), and whale optimizer algorithm (WOA) were applied to improve the dynamic behavior of PMSG (Ali et al., 2014; Mahmoud et al., 2020).

III.MPPT OF VARIABLE SPEED WIND GENERATORS

In this section, the offered WOA are applied to improve the MPPT control strategy of variable speed wind generators. The grid-connected gearless permanent magnet synchronous generator driven by a variable speed wind turbine (VSWTWG) is modeled and simulated using MATLAB/Simulink software. The grid-connected VSWT-WG model, as i Wind turbines arrest wind power and transform it into mechanical energy. Then this mechanical energy is transformed into electrical energy using WG. Finally, the electrical energy is transmitted to the grid through frequency converters.

Wind turbine modeling

The leading type of wind turbines for high wind power construction is the horizontal-axis wind turbine. It converts the kinetic wind energy to rotational energy by its blades. The aerodynamic power Pw of air density ρ flowing at speed vw via a circular area A, as illustrated in

$$P_w = \frac{1}{2}\rho A v_w^3$$

Therefore, the rotational (mechanical) power PM of the turbine shaft, as illustrated in

$$P_M = P_w C_P$$

where the relation between PM and Pw is called a power coefficient CP, which depends on the pitch angle β and tip speed ratio (TSR) or λ as illustrated in (8). The TSR is the relation of blade tip velocity to the wind velocity, as illustrated in

$$C_p(\lambda,\beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{-\frac{18.4}{\lambda_i}}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.02\beta} - \frac{0.03}{1+\beta^3}$$

$$\lambda = \frac{R\omega_m}{v_w}$$

where R is the blade span, and ωm is the mechanical shaft velocity. Regarding, the maximum traced power Pmax by wind turbines can be attained by the optimum value of power coefficient CPopt and λopt where the value of wind velocity is uncontrollable, and the swept area of blades is constant as illustrated in

$$P_{\max} = \frac{1}{2}\rho A\left(\frac{\omega_m R}{\lambda_{opt}}\right)^3 C_{Popt}$$

Frequency converter

The variable-speed wind generator is linked to the grid via a frequency converter, This converter includes two voltage source converters (VSCs) connected in back to back way, where one of them operates as a rectifier, and the other operates as an inverter . The VSC is a two-level converter made of six insulated-gate bipolar transistors (IGBTs) paralleled with anti-aliased diodes A DC- link capacitor (40 mF) is connecting the converters. The cascaded controller activates the converters by pulse-width-modulation (PWM) signal, as shown in Fig. 5 .. The rectifier, which connected to the PMSG, is responsible for maximum power point tracking (MPPT) from the wind turbine generation system. .

MPPT control

In order to run the generator side converter in a rectifier mode, the flux oriented control is used to produce PWM to trigger the IGBTs of the rectifier. Cascaded control of outer and inner loops is used to produce dq-axis reference voltagesThe d-axis current isd is controlled to be zero for a unity power factor operation as in. In , the real power is proportional to the q-axis current isq. Therefore, controlling the real power (Ppmsg) with the maximum power Pmax generates the reference q-axis current, as expressed in The produced reference dq-axis voltages, as in), converted to ABC waveforms, then compared with the triangular waveform to generate PWM. are used to regulate the input errors for MPPT and a unity power factor operation, as indicated in

III. WHALE OPTIMISATION ALGORITHM (WOA)

The Whale optimisation algorithm (WOA) The WOA is a new meta-heuristic optimisation algorithm mimicking the hunting behaviour of humpback whales. An adult humpback whale is as big as a school bus. Fig. 3 shows this mammal. The special thing about the humpback whales is their way of hunting known as the bubble-net feeding method . Humpback whales prefer to hunt school of krill or small fishes near the surface. Humpback whales go down around 12 m down in water then start to produce bubbles in a spiral shape or '9'-shaped path encircles prey then follows the bubbles and moves upward the surface to catch the prey Fig. 1 represents this bubble net behaviour. The humpback whales work in teams of at least two individuals and are not beyond stealing prey from the bubble nets set up by others Bubble-net feeding is a unique behaviour noticed in humpback whales. The mathematical model of encircling prey, bubble net hunting method, search for the prey is described in the following 3 subsections State 2

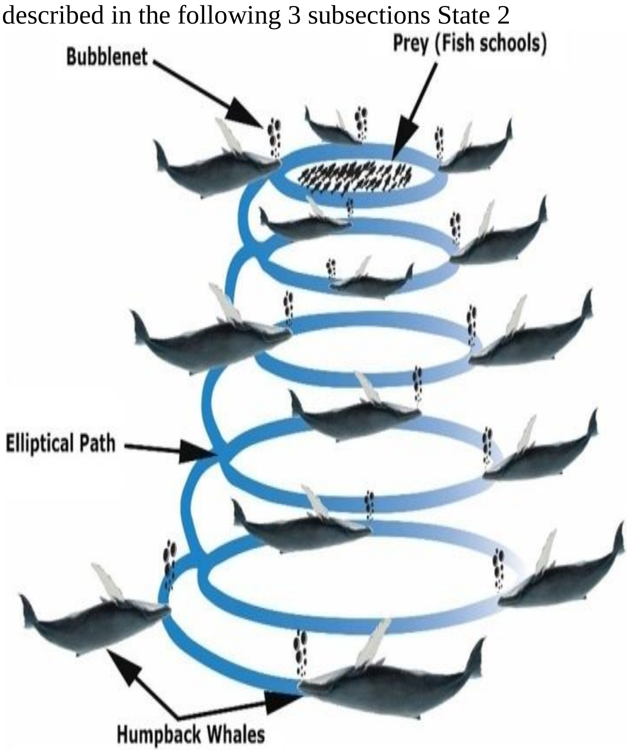


Fig. 1 Bubble-net feeding behavior of humpback whales

Encircling prey equation Humpback whales can notice the prey location and en-circle them, the WOA supposes that target prey is the current best solution. Then the best search agent is defined, accordingly other search agents will update their positions towards the best search agent over the course of increasing number of iteration from start to a maximum number of iteration through the following equations

$$D = \left| C \cdot X^*(t) - X(t) \right|$$

$$X(t+1) = X^*(t) - A \cdot D$$

where t indicates the current iteration, A and C are coefficient vectors, X∗ is the position vector of the best solution obtained so far, X is the position vector. X∗ should be updated in each iteration, if there is a better solution. The coefficient vectors A and C are calculated as follows

$$A = 2\, a * r - a$$

$$C = 2 \cdot r$$

where a is a variable linearly decrease from 2 to 0 over the iterations in both exploration and exploitation phases. Exploration is related to global search exploring the search space looking for good solutions while exploitation is related to local search to refine the solution avoiding big jumps on the search space. r is a random number [0, 1]

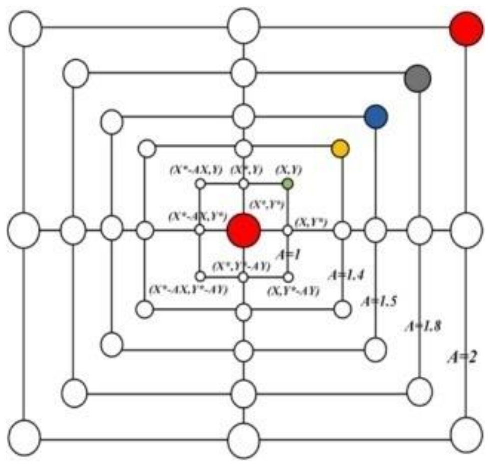
. Bubble-net attacking method
To develop the mathematical equations for bubble-net behaviour of humpback whales, two methods are modelled as follows:

$$X(t+1) = D' \cdot e^{bl} \cdot \cos(2\pi l) + X^*(t)$$

(i) Shrinking encircling mechanism: This technique is employed by decreasing linearly the value of a from 2 to 0 over the course of iterations in (12), causing fluctuation in A in the interval [−1, 1]. The new position of a search agent is anywhere between the original position of the agent and the position of the current best agent. Fig. 4 shows the possible positions from (X, Y) towards (X*,Y*) that can be achieved by 0 ⩽ A ⩽ 1 in a 2D space.

(ii) (ii) Spiral updating position: To update the position of whale located at (X,Y) and prey located at (X*,Y*), a spiral equation is introduced to mimic the helix-shaped movement of humpback whales as shown in Fig. 4b, which is described as

where D′ = X∗ ()−t X( )t and indicates the distance of the ith whale to the prey (best solution obtained so far), b is a constant



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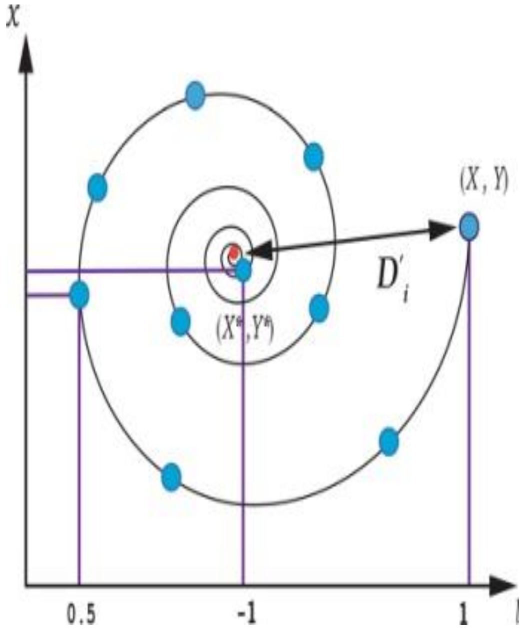

Fig. 2 Bubble-net search mechanism implemented in WOA (X* is the best solution obtained so far) a Shrinking encircling mechanism b Spiral updating position

Fig. 2 Bubble-net search mechanism implemented in WOA (X* is the best solution obtained so far) a Shrinking encircling mechanism b Spiral updating position [16]

for defining the shape of the logarithmic spiral, l is a random number in [−1, 1]. There is a probability of 50% to choose either the shrinking encircling mechanism or the spiral model to update the position of whales

$$X(t+1) = \begin{cases} X^*(t) - A \cdot D & \text{if } p < 0.5 \\ D' \cdot e^{bl} \cdot \cos(2\pi l) + X^*(t) & \text{if } p > 0.5 \end{cases}$$

where p expresses random number between [0, 1].

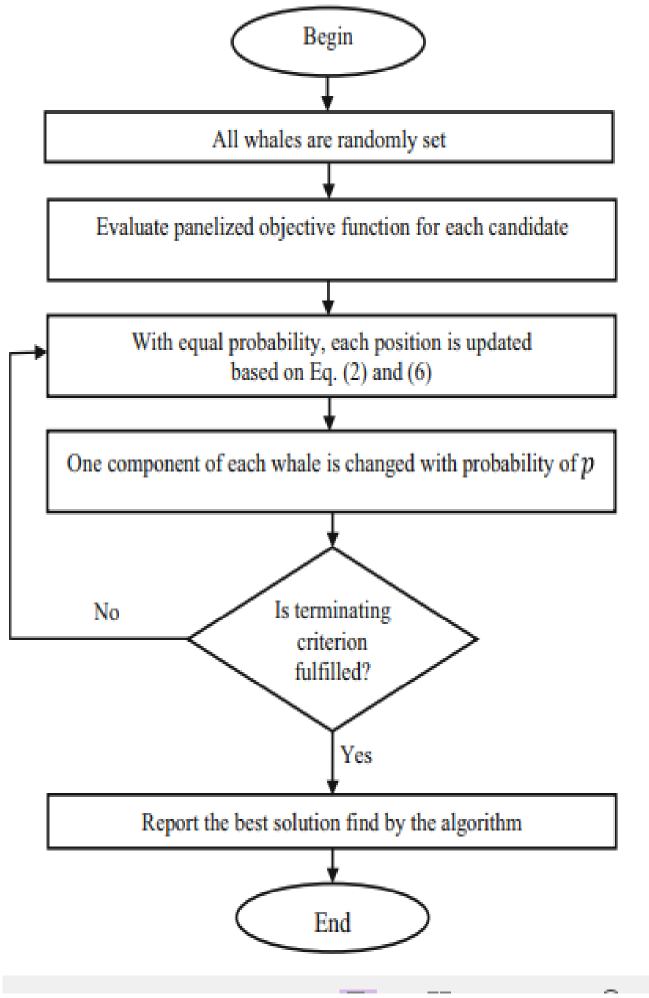

Fig. 3 Flowchart Whale optimization

Pseudo-code of the WOA algorithm.

Initialize the whales populationXi (i = 1, 2, ..., n)
Calculate the fitness of each search agent
X*=the best search agent
while (t < maximum number of iterations)
for each search agent
Update a, A, C, l, and p
if1 (p< 1)
Update the position of the current search agent by the Eq. (2.1)
else if2 (|A|
Select a random search agent ( )
Update the position of the current search agent by the Eq. (2.8) end if2
else if1 (p 0.5) Update the position of the current search by the Eq. (2.5)
end if1
end
for Check if any search agent goes beyond the search space and amend it Calculate the fitness of each search agent Update X* if there is a better solution
t=t+1
end
while return X*

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.IV. RESULTS AND ANALYSIS

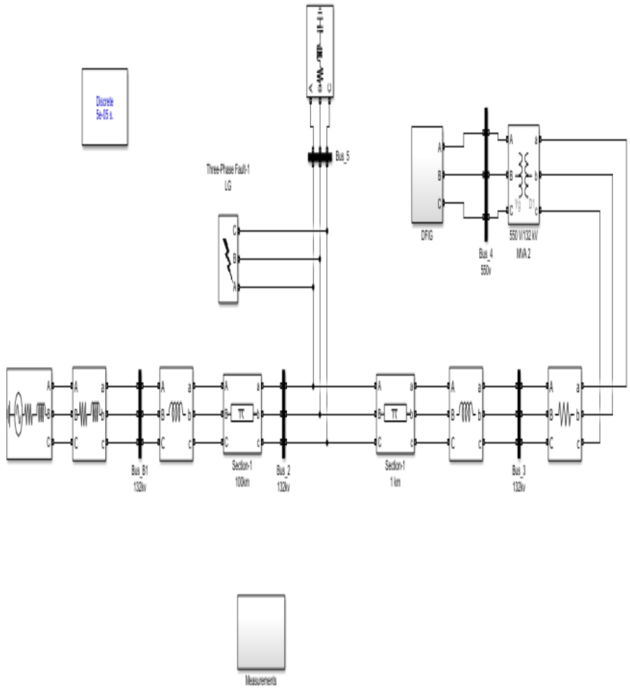

Fig. 4 Simulation Diagram

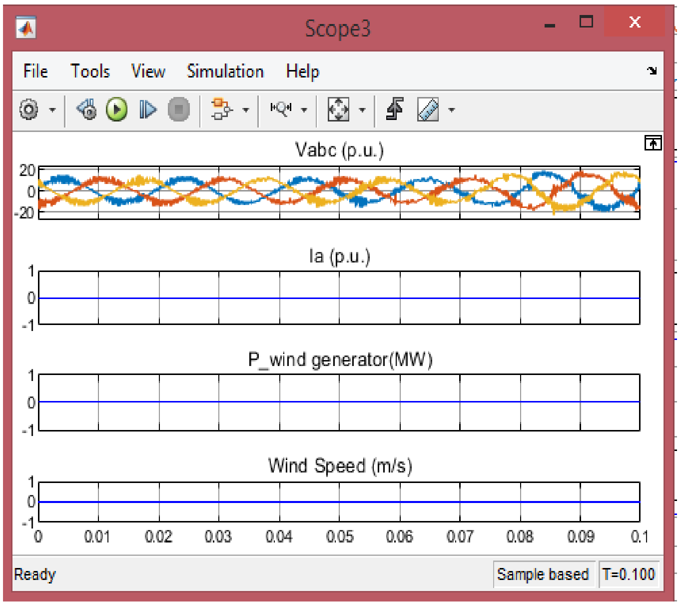

Fig. 5 Simulation Waveform

After the analysis of the design and MPPT mechanism for HWTHS, simulation using Simulink was conducted to verify the proposed method as shown in Figure 5. In this simulation, the parameters used in HWTHS refer to Table 1. The load used in this study is a resistive load with a value 10 Ω.3.1. Performance of PSO MPPT Algorithm for Each System Based on simulation results, the greater the wind speed, the output power of the WES became greater. This also applies to TES, the greater the speed of the tidal, the output power of TES also increased. PSO algorithm which was implemented on HWTHS could increase the output power of each system, both WES and TES. Thus, the efficiency of WES could be increased from 71% to 94% while TES's efficiency increased from 66% to 91%. In the TES, in addition to improve the efficiency of 24%, the use of the PSO algorithm also could maintain system efficiency at 91% where TES's efficiency that did not use MPPT varies between 49-86%. Performance of WES and TES at any wind speed and tidal speed can be seen in Figure 6.3.2. Performance of PSO MPPT Algorithm for HWTHS Based on [9], tidal speed is a function of the ocean wave height as stated in (5). Where U is tidal speed, m was average beach slope (m= 0.033), g is acceleration of gravity (g= 9.8m/s2), H is ocean wave height, and α was the wave breaker angle (α= 15°

V.CONCLUSION

The proposed HWTHS was composed of wind turbine, tidal turbine, rectifier, buck-boost converter, and load. MPPT process was performed on each system, WES and TES. The proposed system had been tested on the range of possible input appropriate to the characteristics of the southern coast of Java. The presented result shows that by using PSO-based MPPT algorithm, maximum power point can be achieved. Thus the efficiency of HWTHS is 92 %, 94 % in wind section and 91 % in tidal section. By using PSO-based MPPT, HWTHS can state System design based on MATLAB software.

Study is summarized as follows: -

1. By using the designed WEC system is preferred over other controlling scheme for high dynamic applications.
2. WEC system with the whale optimization algorithm strategy reduced ripples for the torque by ten times 3. In the speed curve has a lower ripple in the case of Photovoltaic system and reduced by three times when compared other controlling scheme and Photovoltaic system has a lower over shoot after applied torque.

VI. REFERENCE

[1] Aliyu AK, Modu B and Tan CW (2018) A review of renewable energy development in Africa: A focus in South Africa, Egypt and Nigeria. Renewable and Sustainable Energy Reviews 81: 2502–2518

[2] Hossain MM and Ali MH (2015) Future research directions for the wind turbine generator system. Renewable and Sustainable Energy Reviews 49: 481–489

[3] Du W, Dong W and Wang H (2019) Small-signal stability limit of a grid-connected PMSG wind farm dominated by the dynamics of PLLs. IEEE Transactions on Power Systems 35: 2093–2107.

[4] Kadam DP and Kushare BE (2012) Overview of different wind generator systems and their comparisons. International Journal of Engineering Science & Advanced Technology 2(4): 1076–1081.

[5] Kumar D and Chatterjee K (2020) Analysis and enhancement of small-signal stability on DFIG-based wind integrated power system through the optimal design of linear quadratic regulator. IET Renewable Power Generation 14(4): 628–639

[6] [Tripathi SM, Tiwari AN and Singh D (2015) Grid-integrated permanent magnet synchronous generator based wind energy conversion systems: A technology review. Renewable and Sustainable Energy Reviews 51: 1288–1305.

[7] Aguemon DP, Agbokpanzo RG, Dubas F, et al. (2020) A comprehensive analysis and review on electrical machines in wind energy conversion systems. Advanced Engineering Forum 35: 77–93.

[8] Mahmoud MM, Mohamed Hemeida A and Abdel-Rahim AMM (2019) Behavior of PMSG wind turbines with active crowbar protection under faults. In: Proceedings of the 2019 innovations in power and advanced computing technologies (i-PACT), Vellore, India, 22–23 March. New York: IEEE

[9] Shehata EG (2017) A comparative study of current control schemes for a direct-driven PMSG wind energy generation system. Electric Power Systems Research 143: 197–205.

[10] Jahanpour-Dehkordi M, Vaez-Zadeh S and Mohammadi J (2019) Development of a combined control system to improve the performance of a PMSG-based wind energy conversion system under normal and grid fault conditions. IEEE Transactions on Energy Conversion 34(3): 1287–1295.

[11] Qais MH, Hasanien HM and Alghuwainem S (2020) Whale optimization algorithm-based Sugeno fuzzy logic controller for fault ride-through improvement of grid-connected variable speed wind generators. Engineering Applications of Artificial Intelligence 87: 103328.

[12] Ratnam KS, Palanisamy K and Yang G (2020) Future low-inertia power systems: Requirements, issues, and solutions: A review. Renewable and Sustainable Energy Reviews 124: 109773..6450274.