Comparative Analysis of Low Voltage Ride Through Techniques of DFIG Connected to Grid using AI Techniques

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Abstract. The requirement for clean and eco-friendly energy initiated the production of renewable energy. Wind energy promises attractive features such as bulk power production and reduced maintenance cost. Advancement of technologies in the field of wind turbines and generators made the gates open for attractive investments. Adjustable-speed wind turbines tied to Doubly Fed Induction Generators (DFIG) became the most excellent choice of power utilities due to their low-cost power converters and four-quadrant control of useful and wattless powers. The ability to extract a high amount of power for a specified wind speed is a major advantage of DFIG which attracted Power system Operators (PSOs). Low voltage ride-through and wattless Spower support to the grid are estimated and compared using conventional PI controllers, Artificial Neural Network (ANN), and Random Forest Optimization (RFO) algorithm.

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1 Introduction

Global warming along with the continuous diminishing of fossil fuels has found an enhancement in the generation of renewable energy. Wind as well as solar energies are protuberant and promising in sustainable energy sources. The total energy contribution by renewable energy sources in 2021 is 7971 TWh, out of which wind energy contribution is 1862TWh.Per capita, wind energy consumption is highest in Denmark with 721TWh in 2021. India's per capita wind energy consumption is merely 128 MWh in 2021 and its installed capacity reached 40GW in 2021. An assessment made by the National Institute of Wind Energy (NIWE) indicates that there is 36GW of offshore potential near the Gujarat coast and 35GW of offshore potential near the Tamilnadu coast in India. Even though currently no offshore wind firm is in operation, the government of India is planning to set up 17 offshore farms aiming to have 30GW of installed capacity. Technological progress in the field of drives and power electronics has led to various developments in Wind Energy Conversion Systems (WECS).

WECS were employing fixed speed turbines in initial years. Such systems generally employ induction generators of squirrel cage and tied to the grid unswervingly. Hence the generator emf frequency matches the grid frequency. These systems offer the advantages of cost effectiveness WECS were employing fixed speed turbines in initial years. Such systems

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generally employ induction generators of squirrel cage and tied to the grid unswervingly. Hence the generator emf frequency matches the grid frequency. These systems offer the advantages of cost effectiveness combined with simple aerodynamic control. How-ever, they suffer from lack of reactive control and requirement of capacitor stocks are imperative. Energy generated from such WECS is preferably supplied to isolated distribution systems. The 6.5MW wind park located at Ramgiri , Anantapur district of Andhra Paresh is best example for this. Vestas Wind system, A Danish manufacture implemented a new topology which uses wound rotor induction generator. The basic concept behind this topology is rotor resistance mechanism. Rotor resistance is generally controlled by varying the on time of the electronic switch such as IGBT. How ever the speed control achieved by this method hardly 10% around the base speed. Requirement of capacitor banks and energy losses in rotor circuit made this topology absolute in subsequent years. Wind energy conversion systems employing variable speed turbines has overcome the above-mentioned problems. The specialty of these wind turbines is that they can align themselves in the track of the wind and hence maximize the speed and blades can rotate to maximize the power in accordance with maximum power point tracking system. Since the turbine speed varies in harmony with the wind velocity, frequency of the voltage in the rotor circuit varies continuously. To tie-up this system with electric grid, requirement of frequency converter is obligatory which is achieved by power electronic converters tied through DC link. Power quality issues can be minimized since the turbine rotor absorbs much of the mechanical fluctuations. Variable speed WECS employs different types of wind generators, majorly [1].

a. Squirrel cage induction generators.
b. Slip ring induction generators.
c. Permanent magnet induction generators.

Each of these generators has their own pros and cons. WECS using Squirrel cage in-duction generators need to have power converters having the same rating of induction generator. Hence the initial investment of utilities becomes a burden. Permanent magnet induction generators (PMSG) offer the advantages of simple and robust construction along with low power loss. Additionally, the power factor can be controlled. PMSG wind turbine unit doesn’t require a gear box. How ever they are suitable for low and medium power ratings only. Non availability of large size permanent magnets makes this configuration not suitable for high power wind power plants. Demagnetization of permanent magnets may also occur during the operation. Requirement of colling system to maintain temperature within controlled limits adds to additional cost of the system [2]. Slipring induction generators are the most exploited induction generators in wind tur-bine systems. Doubly Fed induction generators are now a days employed in most of the large sized wind power plants, especially in seaward wind power plants.

2 Doubly Fed Induction Generator (DFIG)

These generators are extensively engaged in adjustable speed wind energy systems, especially in large sized wind power plants. The stator of the DFIG is tied to the utility grid while rotor is tied to the grid through power converters. The blade angle of the wind turbine is incessantly adjusted to deliver the maximum output, the output of the DFIG is maximum. The rotor speed of the DFIG continuously varies and hence the frequency of the output voltage also varies. The power converters linked in the rotor act as frequency converters and the frequency of the output is made equal to the grid frequency [3]. Since the converters are connected on rotor side of DFIG, they need to process only slip power. Hence the rating and price of the power electronic converters is reduced which leads to reduced initial cost of the DFIG. Block diagram of DFIG is shown in figure 1.

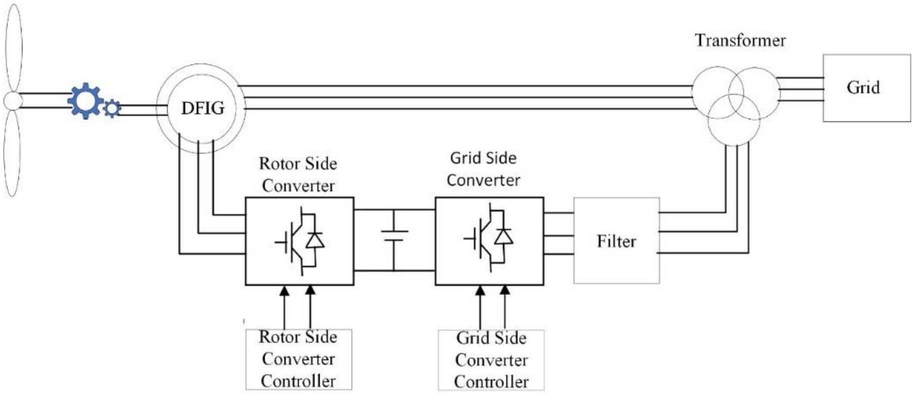

Fig. 1. Block Diagram of DFIG

Equivalent circuit of DFIG rotating at ω in synchronously rotating frame is shown in figure 2[4].

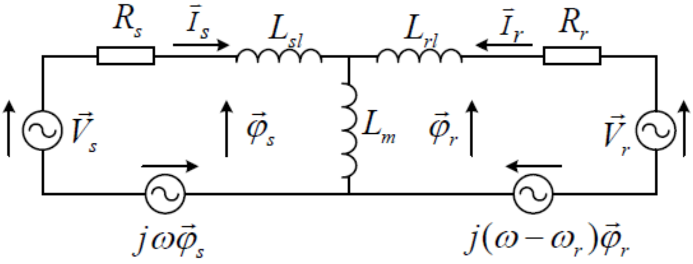

Fig. 2. Equivalent Circuit of DFIG

Flux linkage vectors of stator and rotor are given by

$$\vec{\Phi}_s = L_s\vec{I}_s + L_m\vec{I}_r \tag{1}$$

$$\vec{\Phi}_r = L_r\vec{I}_r + L_m\vec{I}_s \tag{2}$$

Where L_s is the total stator magnetic inductance given by $L_s = L_m + L_{sl}$ and
L_r is the total rotor magnetic inductance given by $L_r = L_m + L_{rl}$
Here is L_{sl} the stator winding inductance due to leakage and
L_{rl} is the rotor winding inductance due to leakage.
L_m is the mutual inductance.
In rotating reference frame, stator voltage vector is described by the equation

$$\vec{V}_s = R_s\vec{I}_s + \frac{d\vec{\Phi}_s}{dt} + j\omega\,\vec{\Phi}_s \tag{3}$$

$$\vec{V}_r = R_r\vec{I}_r + \frac{d\vec{\Phi}_r}{dt} + j(\omega - \omega_r)\vec{\Phi}_r \tag{4}$$

Substituting the above equations in d_s-q_s synchronous frame, we get

$$v_{sd} = R_s i_{sd} + \frac{d\Phi_{sd}}{dt} - \omega\Phi_{sq} \tag{5}$$

$$v_{sq} = R_s i_{sq} + \frac{d\Phi_{sq}}{dt} + \omega\Phi_{sd} \tag{6}$$

Where i_{sd} and i_{sq} are the components of stator current in d_s - q_s synchronous frame

and v_{sd} and v_{sq} are stator d axis and stator q axis components.
Stator useful power and wattless power of a DFIG when implemented in field-oriented control are given by

$$P_s = \frac{3}{2}\frac{L_m}{L_s}\omega_e \Phi_{sd} i_{rq} \quad (7)$$

$$Q_s = \frac{3}{2}\frac{L_m}{L_s}\omega_e \Phi_{sd} \left(\frac{\Phi_{sd}}{L_m} - i_{rd}\right) \quad (8)$$

3 Low Voltage Ride Through (LVRT)

In case of grid faults or voltage dips, since stator of the DFIG is linked to the grid the stator voltage becomes zero. In case of large sized induction machines, stator resistance drop is considerably less compared to its stator voltage and hence can be neglected. From below stator equation, we can say that the stator flux linkage and hence stator RMF is constant.

$$\vec{V}_S^S = R_S \vec{I}_S^S + \frac{d(\vec{\psi}_S^S)}{dt} \quad (9)$$

Now the rotor magnetic field is rotating at ω_r and stator magnetic field is stationary and hence the slip speed is (1-s)ω_s. Generally, the operating slip of any induction machine is around 30%. For a machine rating of 1kV stator rating, under normal working conditions the rotor voltage induced is around 300V and under the conditions of dead short circuit the rotor voltage is around 700V. This enhanced rotor voltage saturates the power converter tied to the rotor. Once the power converter saturates, it cannot synthesize the commands to control rotor current; hence, very high currents flow through the converters. Previous years, Wind Energy Conversion Systems is simply disconnected from the Grid. This disconnection of WECS further worsens the Grid problem [5]. Later years DFIGs were using crowbar circuits. When the crowbar circuit is energized, the DFIG act as squirrel cage induction motor drawing wattless power from the grid. In new grid codes, Wind parks not only should be connected to the grid, but also should pump wattless power to the grid [6]. The ability of wind turbines to be connected to the grid under grid faults or voltage slumps may be defined as Low Voltage Ride Through (LVRT) or Fault Ride Through (FRT).

Crowbar circuit used to protect the DFIG from low voltage ride through in case of grid errors or voltage slumps is shown in figure 3.

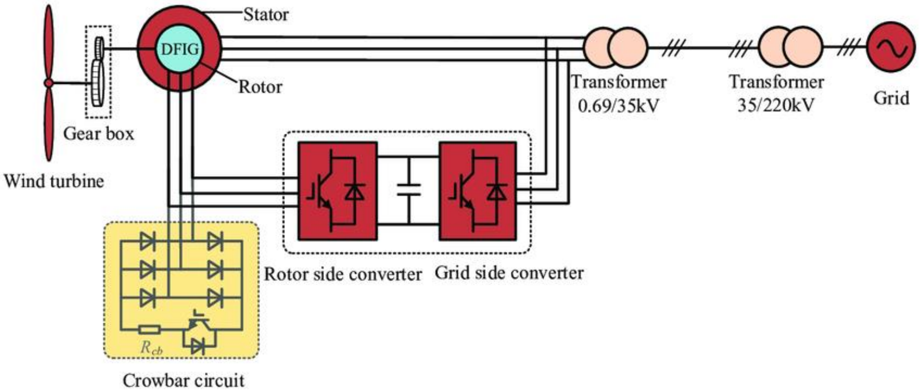

Fig. 3. Crowbar circuit for protection of DFIG

Several types of LVRT techniques discussed in the literature are shown in the form of a flow chart in figure 5.

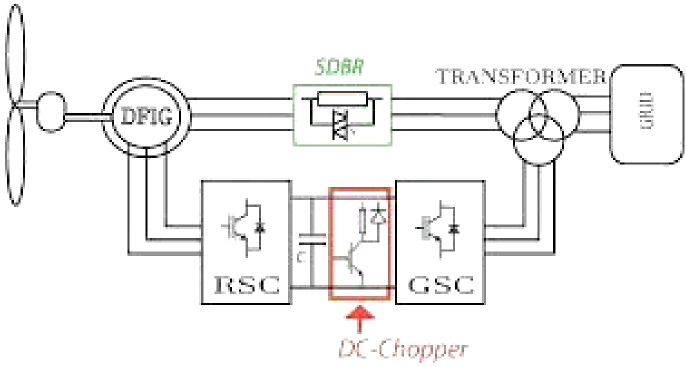

Fig. 4. Chopper Circuit to enhance LVRT of DFIG

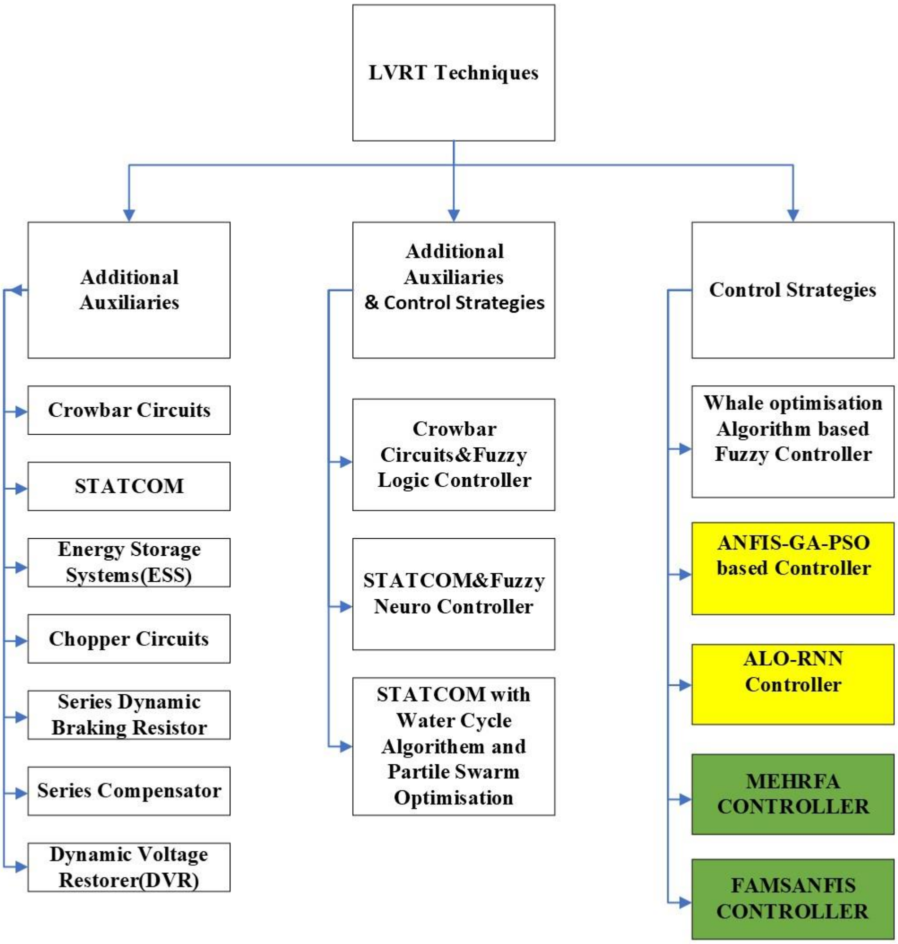

Fig. 5. Flow chart representation of Low Voltage Reide Through techniques.

An alternative method to disable the limitations of crowbar circuit is to impose a chopper circuit in the DC link [8]. The intension of connecting the chopper circuit is to preserve the DC connection voltage persistent and hence to protect the converters from over voltages during grid faults. Such a type of arrangement is shown in figure 4. Requirement of high rating chopper along with huge power loss in the resistor are major limitation of this method.

Energy storage systems (ESS) when connected in DC link of the rotor system has potentiality to control the DFIG during grid faults [9-10]. The limitation of this system is that rotor side converter rating needs to be improved along with additional cost and complexity involved in establishing ESS devices. LVRT enhancement using ESS de-vices is shown in figure 6.

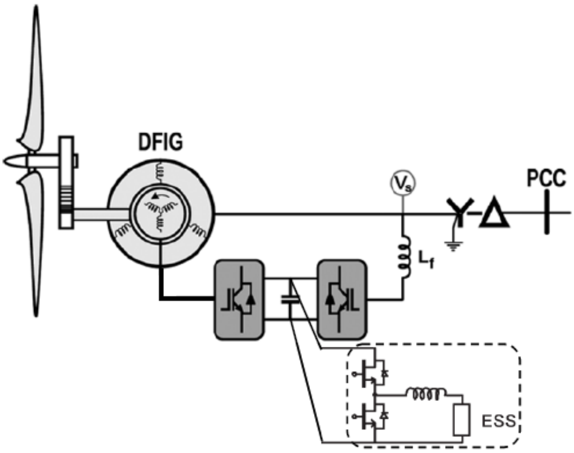

Fig. 6. Chopper Circuit to enhance LVRT of DFIG

4 Simulation and Results

The LVRT methods are classified as additional auxiliaries, additional auxiliaries along with controller designs and only controller designs [11-15]. Addition auxiliary methods even though overcome LVRT issues, they result in additional cost, floor area and complex control strategies. Additional auxiliaries along with controller de-signs are better in technical performance but still they result in additional cost and complex designs. Enhancing the LVRT of DFIG without using additional auxiliaries and just by using artificial intelligent controllers gained the attention of utilities. Many of such techniques were discussed. C.J Madan and N Kumar proposed fuzzy grey wolf optimization for LVRT enhancement[16].R Hiremath and T Moger proposed a new sliding mode controller which uses a modified super twisting algorithm to enhance LVRT of DFIG[17].A Khajeh and R ghazi suggested GA type LQR controller to increase LVRT of DFIG[18].H Ahmadi et all suggested multi objective Krill algorithm which enhances the LVRT during grid faults[19].All the above AI algorithms motivated to implement new controller designs based on soft computing like Random Forest Optimization Algorithm (RFO) which not only enhance LVRT capabilities but also increase the useful power output of DFIG and supply wattless power to the grid under grid errors. A 3.5 kW DFIG is simulated using MATLAB Simulink using conventional PI controller first [20]. The performance parameters like useful power and wattless power of DFIG and wattless power of the grid are plotted during normal and fault conditions. The gains KP and KI are obtained using genetic algorithm first and utilized in subsequent simulations. Here DC link capacitor voltage is the main input which is to be maintained constant during grid faults also. The same machine is simulated using Artificial Neural Network (ANN) controller. In this simulation two ANN controllers are adopted to control useful power and wattless power of DFIG independently [21-22]. A multilayer perceptron model with a structure of 2-7-1 is chosen for the two ANN controllers. Activation function for the hidden layers is chosen as log sigmoid function whereas for input layer it is tan sigmoid function. For output layers activation function chosen is linear function. ANN controller for controlling useful power and wattless power of DFIG is shown in figure 7.

Random Forest Optimization (RFO) algorithm-built controller is chosen to simulate the DFIG [23-24]. It was found that DFIG performance is enhanced compared to conventional PI controller and ANN controllers. The useful power of DFIG fed to the grid in normal and fault conditions and wattless power assistance to the grid is more com-pared to conventional PI and ANN controllers.

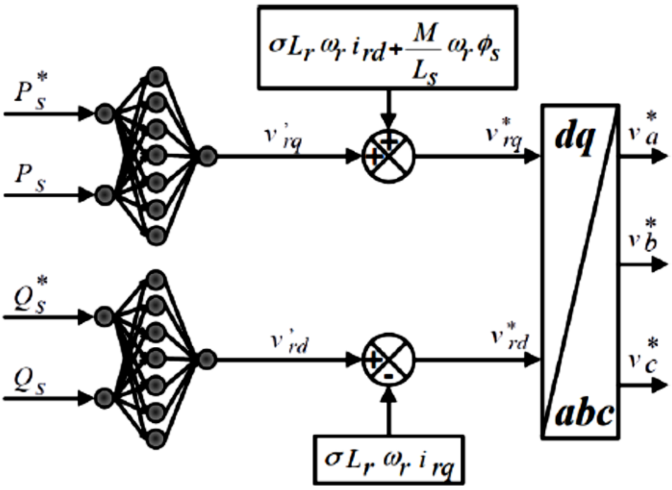

Fig. 7. ANN controller to control active and reactive powers of DFIG

Random Forest Optimization (RFO) algorithm is the most utilized, diversified, and simple algorithm. A major advantage of this algorithm is it can be used for both classification and regression tasks. It is a supervised learning algorithm in which a forest is created by utilizing many models to achieve the best performance. The RFO algorithms uphold very good accuracy. This algorithm is used to simulate the DFIG connected to grid. The useful power and wattless powers of DFIG and grid wattless power are plotted using conventional PI , ANN and RFO method and compared.

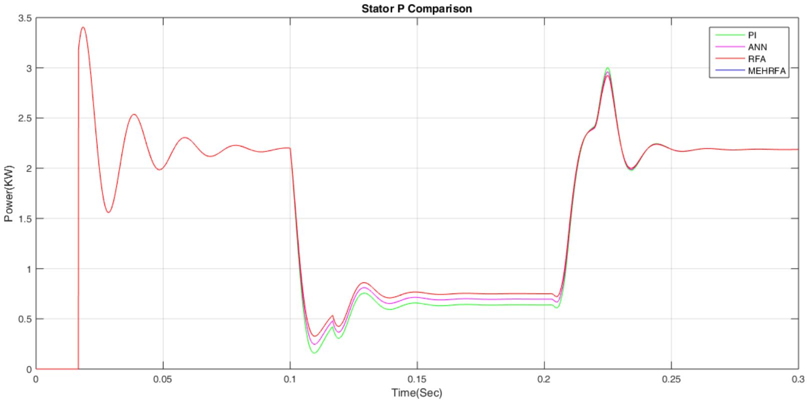

Fig. 8. Stator active power of DFIG for different controllers

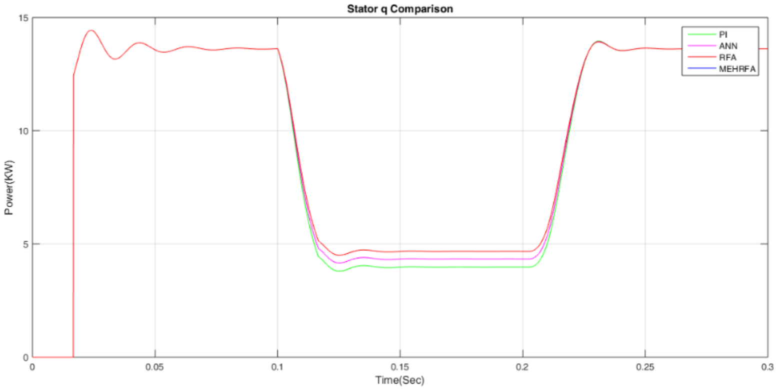

Fig. 9. Stator reactive power of DFIG for different controllers

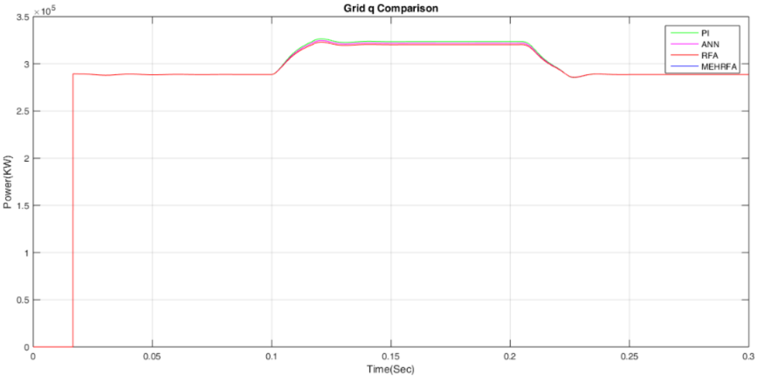

Fig. 10. Grid reactive power of DFIG for different controllers

Table 1. Table of useful wattless powers of DFIG and grid wattles power..

Name of the method	Useful power of DFIG	Wattless power of DFIG	Grid wattles power
PI Controller	0.7 KW	0.55 KVAr	28 KVAr
ANN Controller	0.74 KW	0.65 KVAr	27 KVAr
RFO Controller	0.77KW	0.75 KVAr	26.2 KVAr

5 Conclusion

Causes and probable solutions of low voltage ride through of doubly fed induction generator are discussed thoroughly. Doubly fed induction generator connected to grid was simulated in MATLAB Simulink using controllers conventional PI controller, artificial neural network controller and Random Forest optimization controller. It was found that the performance of the DFIG is superior in RFO controller compared to ANN and conventional PI controllers. Useful power and wattless power supplied by the DFIG is higher in RFO controller.

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