REDUCTION OF HARMONICS IN GRID CONNECTED DFIG WIND ENERGY CONVERSION SYSTEM USING INDIRECT CURRENT CONTROL TECHNIQUE

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Abstract: *— As the wind penetration into the grid increasing at a rapid rate, the use of adjustable speed wind energy conversion systems with ancillary services such as power smoothening and harmonic mitigation is essential in addition to its power generation. This paper proposes an indirect current control technique for the grid-side converter (GSC) of DFIG-based wind energy conversion system with fuzzy controller. The proposed DFIG works as an active filter along with the active power generation similar to ordinary DFIG. This wind energy conversion system also works as a static compensator (STATCOM) for providing harmonics even when the wind turbine is in stalling condition. The proposed wind energy conversion system is simulated using MATLAB/Simulink and the steady state performance of the system is validated.*

Keywords: *doubly fed induction generator, wind energy conversion system, hysteresis controller, fuzzy controller, nonlinear load.*

1. Introduction:

Till today, most of the electricity have been generated from conventional fossil sources, which are mostly non-renewable sources such as gas, oil and coal. This kind of energy conversion discharges a large amount of carbon dioxide to the atmosphere, which results in global warming [1, 2]. For this reason and also due to rapid growth of modern electricity production tools, the renewable energy converters are most chosen because of their smaller size, lower cost per unit and being more eco-friendly compared to conventional sources [3, 4]. Due to practical improvements in the wind technologies the cost of wind power is low compared to that of other renewable energy sources. Therefore, wind energy is most chosen out of all renewable energy sources.

The key constituents of wind energy conversion systems are generator and turbine. The characteristic of turbine is such that it has good conversion efficiency at certain rotational speed matching to certain wind speed and the efficiency drops in both ways. Up to the present, the majority of the wind energy conversion systems are based on fixed speed induction generators (FSIG) which do not run effectively during the most of the time and draw large reactive power [5, 6-10]. The grid failures are more due to large reactive power drawn by the wind farms. Now a days variable speed induction generators using power electronic (PE) converter are chosen because they run at a preferred speed, by which turbine can be made to run effectively at all wind speeds. Out of all adjustable speed wind turbines, doubly fed induction generators are chosen because of their low cost, higher energy output, lesser converter rating [11].

2. Configuration of proposed system:

Fig. 1 shows the configuration of proposed DFIG based wind energy conversion system [12]. Here, the stator of the DFIG is directly fed to the grid and the rotor is fed to the grid through two back-to-back voltage source converters (VSC’s). Therefore, the grid frequency is maintained constant. The nonlinear loads are connected at the point of common coupling (PCC) due to this harmonics are generated at PCC which will distort the grid currents. The grid side converter of the DFIG is controlled by an indirect current control using PI and fuzzy controllers to compensate harmonics.

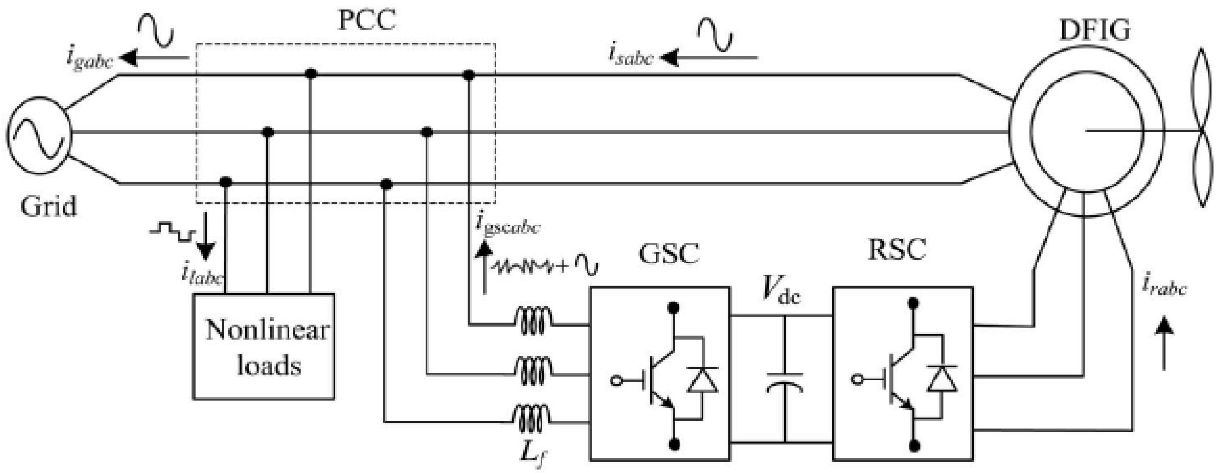


Fig. 1. Configuration of proposed system

3. Indirect current control strategy:

The control algorithm for grid side converter is shown in Fig. 2. Here, an indirect current control technique is applied on the grid currents to make them sinusoidal. Thus grid side converter supplies the harmonics for making grid currents sinusoidal and balanced. These grid currents are obtained by subtracting the load currents from the sum of grid side converter currents and stator currents. The active power component of grid side converter current is obtained by using PI controller by processing DC-link voltage error as given in (1):

$$i^*_{gsc}(k) = i^*_{gsc}(k-1) + k_{pdc}\{v_{dce}(k) - v_{dce}(k-1)\} + k_{idc}v_{dce}(k) \quad (1)$$

where k_{pdc} and k_{idc} are proportional and integral gains of DC-link controller respectively. $v_{dce}(k)$ and $v_{dce}(k-1)$ are DC-link errors at k^{th} and $(k\text{-}1)^{th}$ instants respectively. $i^*_{\mathrm{gsc}}(k)$ and $i^*_{\mathrm{gsc}}(k-1)$ are active power components of grid side converter current at k^{th} and $(k\text{-}1)^{th}$ instants respectively.Active power component of stator current (i_{ds}) is calculated by the sensed stator currents (i_{sa}, i_{sb}, i_{sc}) using *abc-dq* transformation as given in (2):

$$i_{ds} = 2/3\left[i_{sa}\sin\theta_e + i_{sb}\sin(\theta_e - \frac{2\pi}{3}) + i_{sc}\sin(\theta_e + \frac{2\pi}{3})\right] \quad (2)$$

Direct axis reference grid current (i^*_{gd}) component is obtained from the direct axis stator current (i_{ds}) and load current ($\overline{\iota_{ld}}$) in synchronously rotating reference frame and the loss component of GSC current (i^*_{gsc}) as given in (3):

$$i^*_{gd} = i^*_{gsc} + i_{ds} - \overline{\iota_{ld}} \quad (3)$$

Quadrature axis reference grid current (i^*_{gq}) component is selected as zero for not to draw any reactive power from grid. Reference grid currents are calculated from direct and quadrature axis currents (i^*_{gd}, i^*_{gq}). The hysteresis controller is used to generate firing pulses for the grid side converter. It is normally a feedback current controller where measured current tracks reference current within hysteresis band i_{hb}. At every instant, the actual current (i_{gabc}) is compared to the reference current (i^*_{gabc}) as given in (4):

$$\Delta i_{gabc} = i^*_{gabc} - i_{gabc} \quad (4)$$

when $\Delta i_{gabc} > i_{\mathrm{hb}}$, lower switches of the GSC are turned ON.

when $\Delta i_{gabc} < -i_{\mathrm{hb}}$, upper switches of the GSC are turned ON.

Using these equations, firing pulses for three phases of grid side converter are generated.

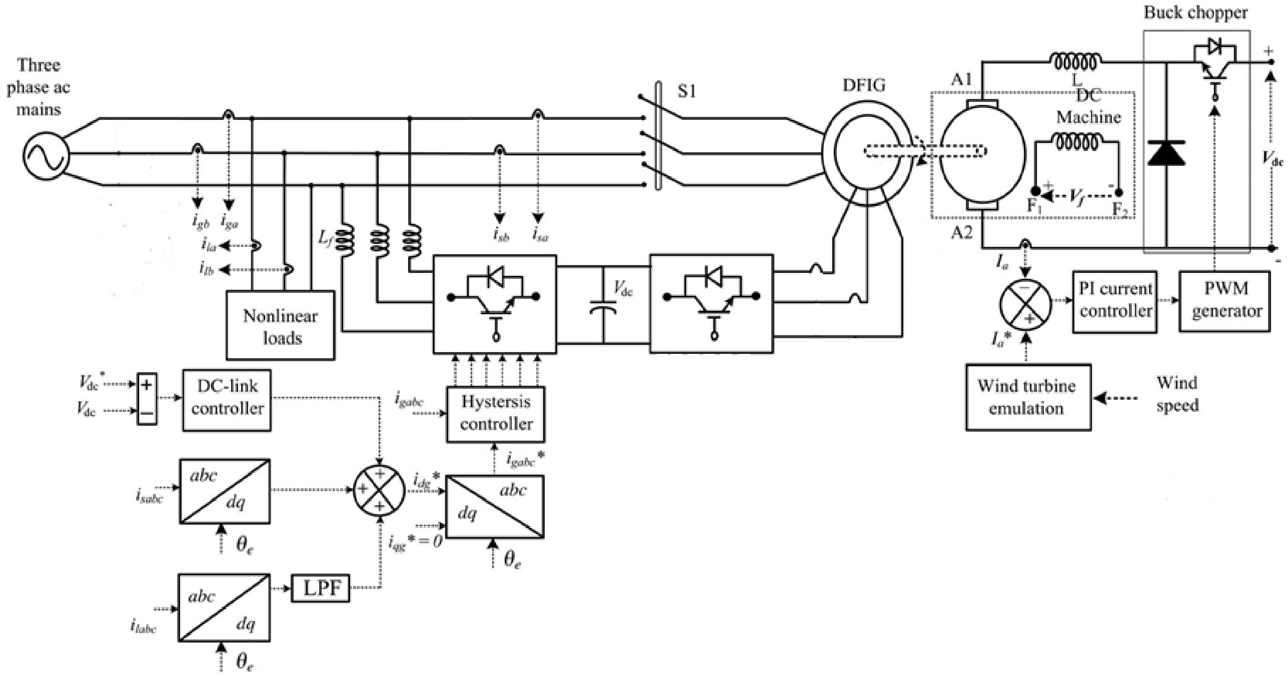
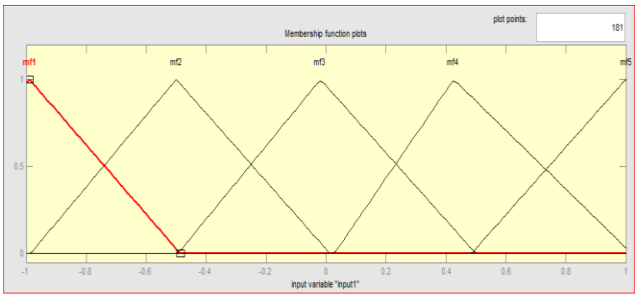


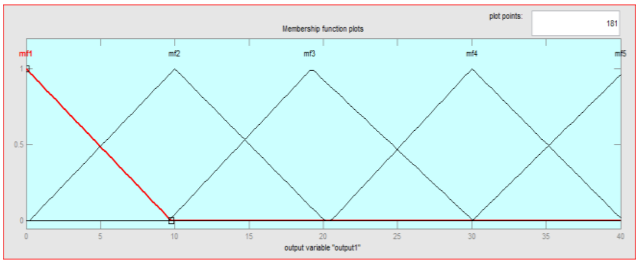
Fig. 2. Control technique of proposed system.

4. Fuzzy logic controller:

The fuzzy logic controller uses the fuzzy rules to obtain the desired control applications [13]. Fuzzy rules have been developed based on the control rules. Fuzzy logic systems are not designed based on mathematical models. Fuzzy controllers implement the human logic using fuzzy logic that is planned by membership functions, fuzzy rules. In this work, the DC-link output voltage is compared with the reference voltage and the generated error signal and its derivative is applied to the controller as the controller inputs. A fuzzy system is described by a set of IF-THEN rules and uses a number to define the degree of membership in its membership functions. To solve the problem in fuzzy controller, controller inputs, error signal and its derivation, and its output are considered as the control signal.



(a)



(b)

Fig. 3. The membership functions of proposed fuzzy controller (a): input and (b): output

In this work 5-segment triangular membership functions are used. Each input has five membership functions, so the number of base fuzzy rules is 25. The fuzzy rules of fuzzy controller are shown in Table 1.

Table 1. Fuzzy rules of proposed fuzzy controller

V^*_{dce} / V_{dce}	NB	NS	ZZ	PS	PB
NB	S	S	M	M	B
NS	S	M	M	B	VB
ZZ	M	M	B	VB	VB
PS	M	M	VB	VB	VVB
PB	B	VB	VB	VVB	VVB

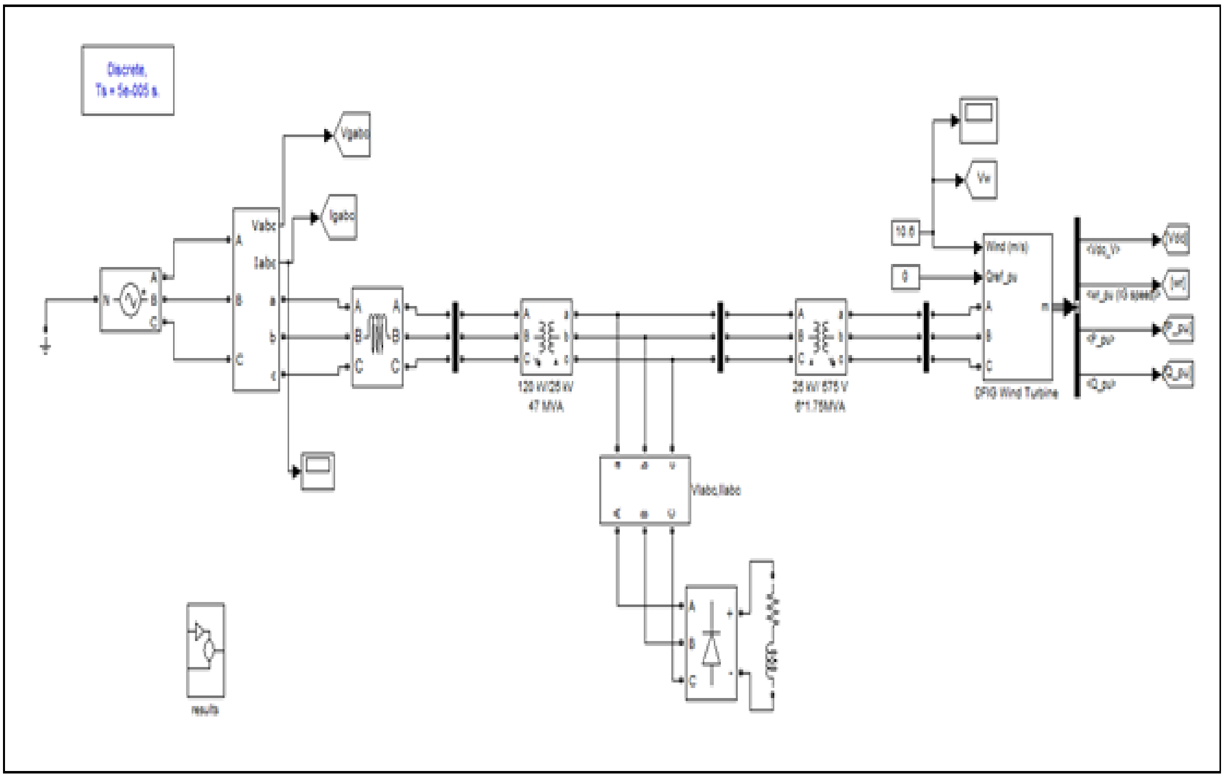


Fig. 4. Simulation model of proposed system

4. Simulation model of proposed system:

The proposed DFIG based wind energy conversion system with an indirect current control technique applied for Grid side converter is simulated in MATLAB/SIMULINK. The non-linear load is connected at PCC and the DFIG system is connected to grid is shown in Fig.4. The wind speed input is taken as 10.6 m/s. In the proposed system the grid voltage is taken as 120kV maintained at 50Hz frequency and the wind energy conversion system is 9MW which consists of 6 wind turbines. PI controller is used as DC-link controller, the parameters used in simulation are shown in Table 2.

Table 2: Parameters used in simulation

Parameter	Value	Unit	Component
Nominal power	1.67	MVA	DFIG
Nominal voltage	575	V	
Nominal speed	1750	RPM	
wind velocity	10.6	m/s	Turbine
Nominal power	1.5	MW	
Nominal voltage	120	kV	Grid
Frequency	50	Hz	
K_p	0.8		GSC
K_i	6		

5. Results:

The detailed simulation model of the proposed wind energy conversion system was simulated using MATLAB/Simulink. The system consists of a 120kV grid with a 1.5-MW wind turbine. Parameters of this system are shown in Table 2. The simulated performance of the proposed DFIG system using PI controller is presented at a 10.6-m/s wind speed as shown in Fig. 5 and also at stalling condition is shown in Fig. 6.

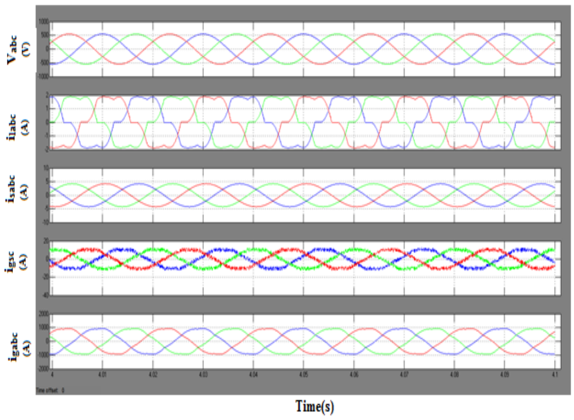


Fig. 5. Simulated performance of the proposed DFIG-based WECS at wind speed of 10.6 m/s with PI controller.

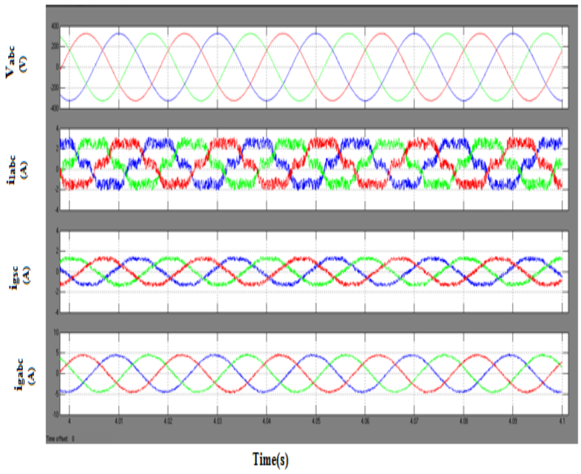
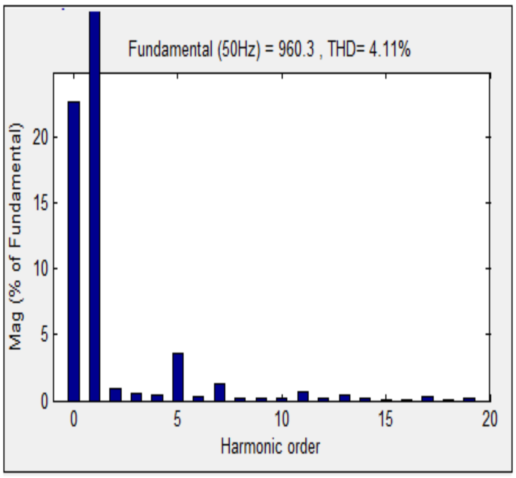


Fig. 6. Simulated performance of the proposed DFIG-based WECS at wind speed of 0 m/s with PI controller.



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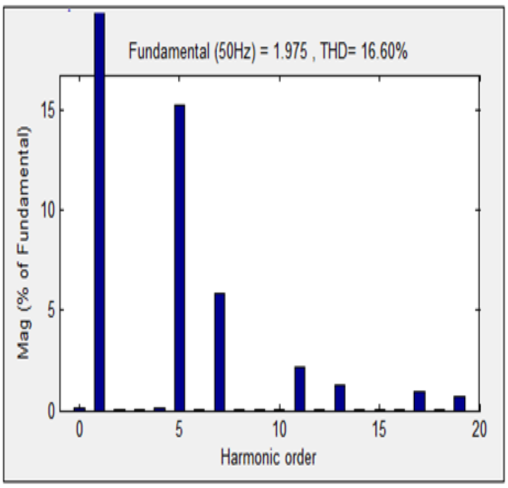
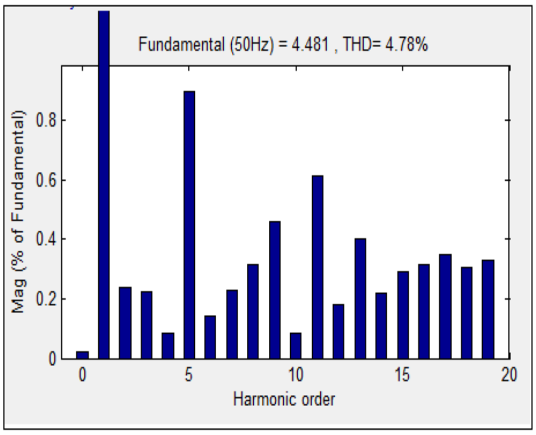


(b)

Fig. 7. Harmonic spectra of (a) grid current (i_{ga}), (b) load current (i_{la}), at wind speed 10.6 m/s.



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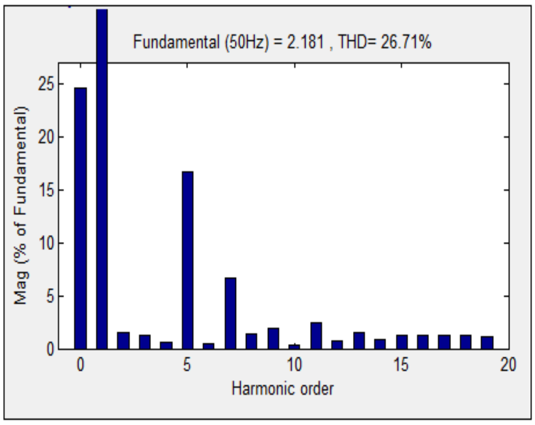


(b)

Fig. 8. Harmonic spectra of (a) grid current (i_{ga}), (b) load current (i_{la}), in stalling condition.

Fig. 7 (a)–(b) shows harmonic spectra of grid current (i_{ga}), load current (i_{la}), respectively at wind speed 10.6 m/s using PI controller. From these harmonic spectra, the grid current and load current THDs are observed to be 4.11% and 16.60% respectively which are less than 5% as per IEEE-519 standard. Similarly, Fig.8 (a)–(b) shows harmonic spectra of grid current (i_{ga}), load current (i_{la}), respectively at wind turbine in stalling condition using PI controller. From these harmonic spectra, the grid current and load current THDs are observed to be 4.78% and 26.71% respectively which are less than 5% as per IEEE-519 standard.

The simulated performance of the proposed DFIG system using fuzzy controller is presented at a 10.6-m/s wind speed as shown in Fig. 9 and also at stalling condition is shown in Fig. 10. The load currents are observed to be nonlinear in nature. The GSC will supply the required harmonic currents to the load for making grid currents (i_{gabc}) and stator currents (i_{sabc}) balanced and sinusoidal.

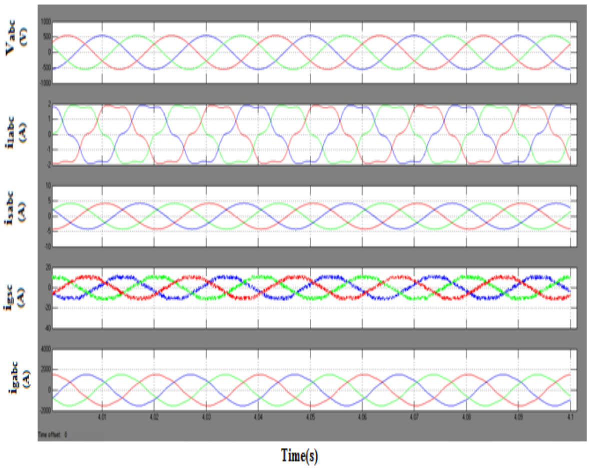


Fig. 9. Simulated performance of the proposed DFIG-based WECS at wind speed of 10.6 m/s with fuzzy controller.

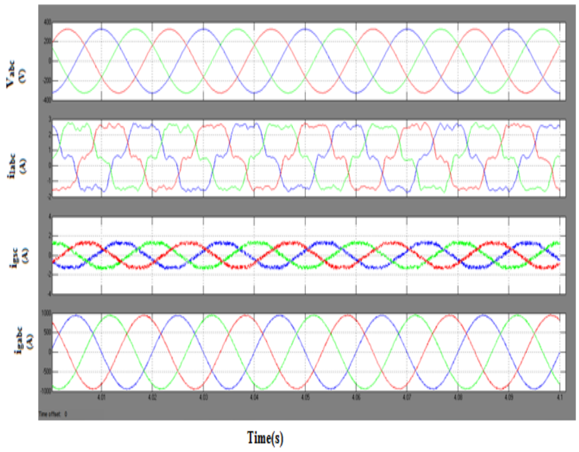
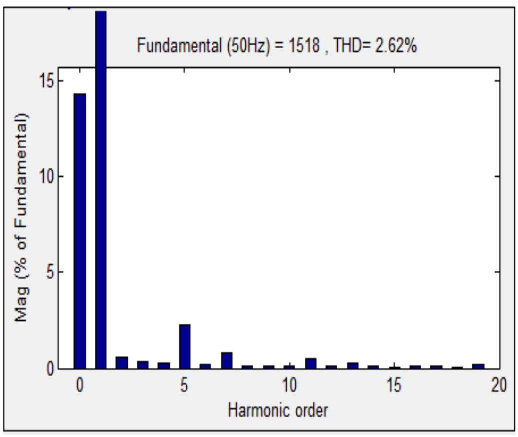
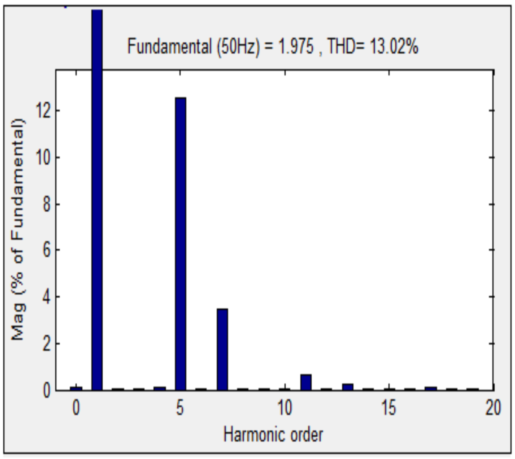


Fig. 10. Simulated performance of the proposed DFIG-based WECS at wind speed of 0 m/s with fuzzy controller.

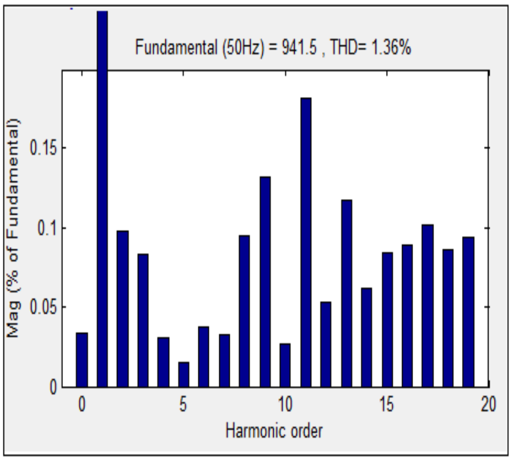


(a)

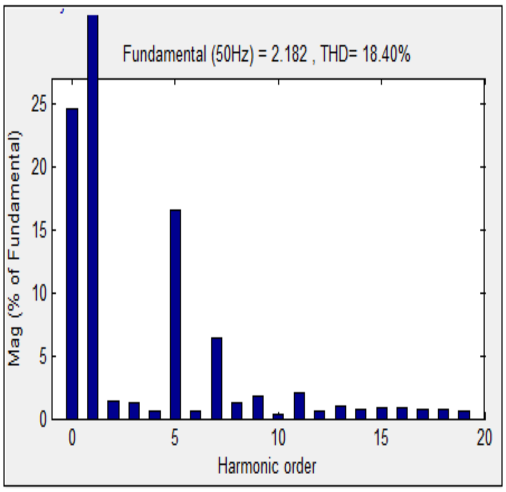


(b)

Fig. 11. Harmonic spectra of (a) grid current (i_{ga}), (b) load current (i_{la}), at wind speed 10.6 m/s.



(a)



(b)

Fig.12. Harmonic spectra of (a) grid current (i_{ga}), (b) load current (i_{la}), in stalling condition.

Fig. 11 (a)–(b) shows harmonic spectra of grid current (i_{ga}), load current (i_{la}), respectively at wind speed 10.6 m/s using fuzzy controller. From these harmonic spectra, the grid current and load current THDs are observed to be 2.62% and 13.02% respectively which are less than 5% as per IEEE-519 standard. Similarly, Fig. 12 (a)–(b) shows harmonic spectra of grid current (i_{ga}), load current (i_{la}), respectively at wind turbine in stalling condition using fuzzy controller. From these harmonic spectra, the grid current and load current THDs are observed to be 1.36% and 18.40% respectively which are less than 5% as per IEEE-519 standard.

6. Comparison of Results:

Table 3: THD comparison between PI and fuzzy controllers.

THD	Controller	Grid current	Load current
Wind speed 10.6 m/s	PI	4.11%	16.60%
	Fuzzy	2.62%	13.02%
Wind speed 0 m/s	PI	4.78%	26.71%
	Fuzzy	1.36%	18.40%

7. Conclusion

Thus the DFIG-based wind energy conversion system was presented with an indirect current control technique for controlling grid side converter. Therefore this GSC will supply the harmonics which makes the grid currents sinusoidal and balanced. The proposed DFIG system is designed and analysed with PI and fuzzy logic controllers. The performance of the system is better with fuzzy logic controller compared to that of PI controller since, the THD for the grid current using fuzzy controller is less compared with PI controller. The proposed DFIG has also been verified at wind turbine shutdown condition for compensating harmonics.

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