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DIRECT FOC ON GRID CONNECTED DFIG BASED WT FOR BETTER PERFORMANCE

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ABSTRACT

In this work, a direct field-oriented control (FO_C) scheme is implemented on rotor side converter (RSC) for a wind farm of 6x1.5 MW capacity using doubly fed induction generator (DF_IG). Less harmonic contents and low power ripples (as per IEEE Standard 1547) are the main advantages of the implemented control scheme in comparison to traditional control schemes like PWM, SPWM and third harmonic rejection schemes etc. The steady-state performance and voltage sag phenomen on is studied in detail. The detailed model (discrete), composed of large number of nonlinear differential equations, is solved using Tustin/Backward Euler (TBE) fixed -step solver in MATLAB/SIMULINK environment. The step size of each iteration is 5 microseconds for better performance.

Keywords*: Doubly Fed Induction Generator (DF_IG), Field Oriented Control (FO_C), Grid Side Controller, Rotor Side Controller, Voltage sag, Wind Turbine (WT).*

I. INTRODUCTION

WITH society heading towards a future atmospheric disaster, the society desperately needs inventions in production of green energy. Renewable sources of energy are showing very rapid expansion in market by effectively replacing the conventional sources of energy [1].

Wind energy is a future-promising renewable energy resource, expanding vastly all around the globe. It is predicted that by 2020, Europe will have nearly 20% of their power requirements fulfilled through wind energy. Developed countries, other than Europe, such as China and USA are also much ahead in the market of wind power resources [2].

Wind turbines (WTs) along with gearbox and electrical generator constitute to the Wind energy conversion system (WECS). There are broadly two classifications of WT technologies- variable and fixed speed [3]. Variable-speed WTs are preferred due to their key advantages which include maximum power capture, reduced stress on mechanical components, enhanced power quality, and less noise [4]. The variable speed technologies can further be divided into: permanent magnet synchronous generators and asynchronous generators. The asynchronous generators are further classified as SEIG and DF_IG. DF_IG is preferred over SEIG due to various advantages such as better reactive power control, reduction in loss of power, less converter cost.

There are various control techniques used in DF_IG based wind turbines. The conventional techniques such as V/f control, PWM and SPWM techniques and third harmonic rejection schemes etc. show good steady state, but poor dynamic performance. To enhance the dynamic performance of the DF_IG based WECS, newer techniques such as FO_C and DTC are being implemented nowadays. Good steady state performance, lower power ripples and reduced switching frequency are the key advantages of field-oriented control [5].

Field-oriented control is mainly of two types, which are usually employed on a DF_IG- sensored (indirect) and sensorless (direct) [6]. In this work direct field-oriented control strategy is employed on the DF_IG based wind turbine system.

Amongst all types of disturbances occurring in a grid, the unsymmetrical faults happen very frequently. The oscillatory nature of the stator output power and electromagnetic torque are some of the major issues occurring in DF_IG under faulty conditions [7].

These disturbances give rise to an important power quality concern of voltage sag occurring in the wind generation system. Voltage sags which last even only for 4-5 cycles, are themselves capable to affect wide range of customer-end equipments. Also, voltage ripples are generated in the DC-link as a consequence of the unsymmetrical faults occurring in the DF_IG that can cause harm to the DC-link capacitance.

Power acceptability is an important concern, since it describes whether the electric power delivered to load from the source is compatible with load characteristics. Voltage sag is, thus, an important issue to be addressed for better performance of DF_IG based wind turbine.

Therefore, in context to this work, two main concerns are studied here. The first one is the implementation of direct field-oriented control strategy on RSC of the DF_IG based wind turbine for control of generated real and reactive powers individually. This is done under the normal operating conditions of the system. Secondly, the model is then restudied under condition of 0.5 p.u. voltage sag for to analyse the performance under faults and compare it with the one under normal operation.

II. FIELD ORIENTED CONTROL

Field-oriented control (FO_C) is commonly used in doubly-fed induction generator. It enables to control, separately, the real and reactive power of the generator. Field-oriented control can be implemented in DF_IGs by using anyone of two types of reference frames, namely- stator voltage-oriented control (SVO frame) and stator flux-oriented control (SFO frame).

The real and reactive powers of stator are [3]:

$$P_s + jQ_s = \frac{3}{2}Re(V_s i_s *) + j\frac{3}{2}Im(V_s i_s *)$$

$$= \frac{3}{2}\left(V_{ds} i_{ds} + V_{qs} i_{qs}\right) + j\frac{3}{2}\left(V_{qs} i_{ds} - V_{ds} i_{qs}\right) \quad (1)$$

For SVOF being used for synchronizing controllers, V_{qs} becomes zero and the equations for stator real and reactive power reduce to

$$P_s = \frac{3}{2} V_{ds} i_{ds} \quad (2)$$

$$Q_s = \frac{-3}{2} V_{ds} i_{ds} \quad (3)$$

Further, the equations for stator current in a reference frame which is rotating at synchronous speed are given as

$$i_{ds+j} i_{qs} = a i_{dr} + a\left(i_{qr} + \frac{V_{ds}}{b}\right) \quad (4)$$

Solution of the above equations leads to

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$$P_s + jQ_s = 1.5aV_{ds}i_{dr} + j\,1.5aV_{ds}\left(i_{qr} + \frac{V_{ds}}{b}\right) \quad (5)$$

where P_s - total stator real power
Q_s- total stator reactive power
V_{ds}-d-axis stator voltage
i_s- total stator current
L_m- mutual inductance
L_s- stator inductance
i_{ds} –stator d-axis current
i_{qs} –stator q-axis current
$a = \frac{-L_m}{L_s}; b = w_s\frac{L_m * L_m}{L_s}$

Thus, i_{ds} and i_{qs} respectively control the stator real and reactive powers.
Field-oriented control is implemented to RSC to regulate the powers of the stator. The d-axis loop controls the reactive power whereas the q-axis loop is for real power control [8]. In RSC, stator flux-oriented control is applied [9].

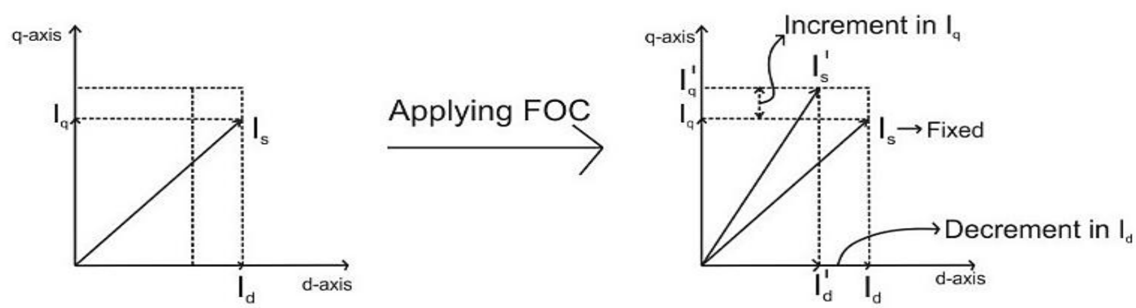

Fig.1. Phasor diagram of field-oriented control strategy

Fig.1 shows the phasor diagram of field oriented control strategy. The left hand side shows the stator current I_s as the phasor sum of its direct axis and quadrature components I_d and I_q respectively. The stator current is kept fixed while applying FO_C on the system.Thus,during implementation of vector control, the current compnents, I_d and I_q adjust themselves to maintain the stator current I_s constant, as depicted in the above figure.All the currents shown in the above figure are in rms value. The block diagram of RSC-based FO_C is shown in Fig.2.

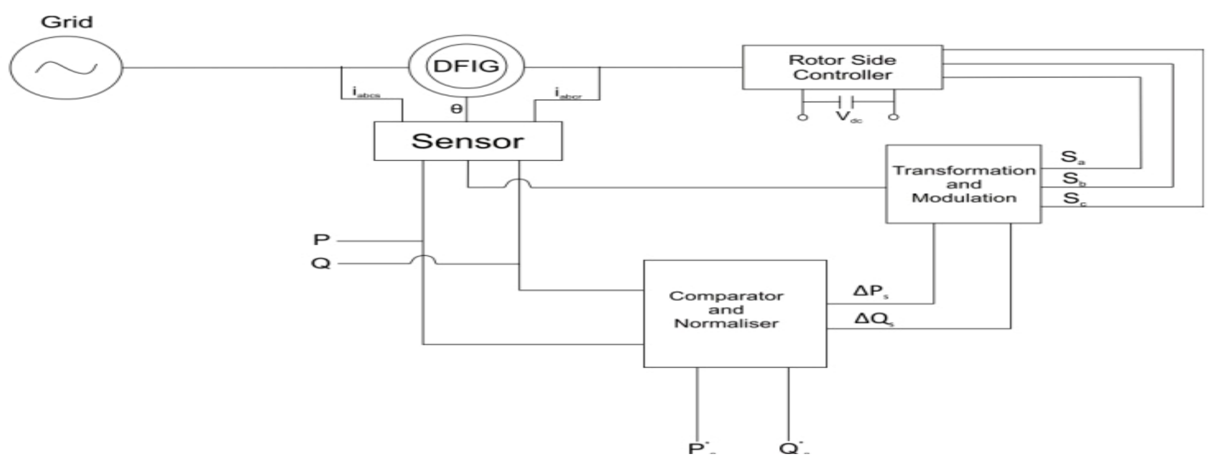

Fig.2. Block diagram of field oriented controlled RSC

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III. VOLTAGE SAG PHENOMENON IN POWER SYSTEMS

Among the various power quality issues, the ones of utmost concern are voltage sags and momentary power interruptions. Industries and large commercial customers are greatly affected by such power quality concerns. These mainly occur due to any fault occurring in the power system.

During voltage sag condition, it is found that high currents are induced in the rotor circuit of DF_IG, this condition may damage the rotor as well as the gearbox of the DF_IG. This condition occurs due to heavy structure of DF_IG. It is recommended that during this adverse condition the DF_IG must remain connected with the grid [10-12].

Further, it is required that during voltage sag condition, the gap of the voltage dip must be filled with the reactive power, which is being supplied by rotor circuit.

IV. SIMULATED RESULTS

In this work a direct field-oriented control (FO_C) scheme is suggested for a wind farm of 6x1.5 MW capacity using doubly fed induction generator (DF_IG). The detailed model composed of nonlinear differential equation is developed and solved using Tustin/Backward Euler (TBE) fixed-step solver in MATLAB/Simulink environment using rotor reference frame theory. Fig.3 gives the block diagram of simulated system with parameters given in Appendix.

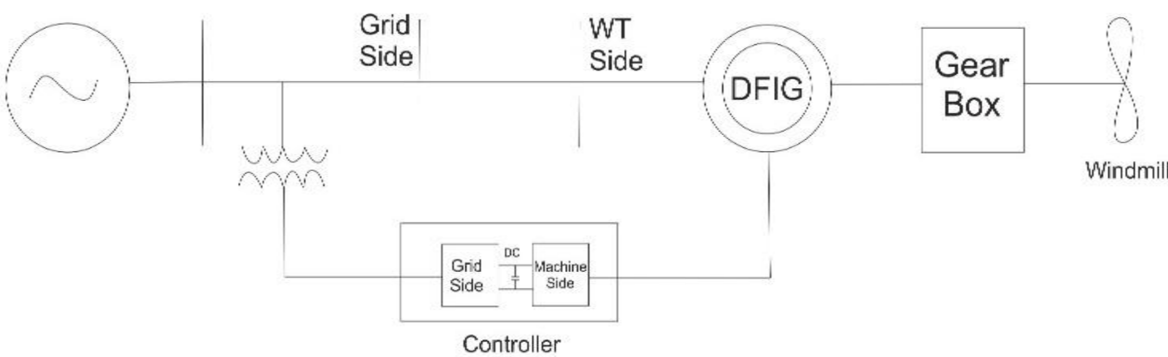

Fig.3.Block diagram of simulated system

Under normal operating condition:
The model is simulated for time 0 < t <0.2 sec under normal operating condition, employing FO_C. The assumed fixed wind speed is 14 m/s when the generators rotate at 1.2 p.u. based on the simulated optimal power-speed curve.

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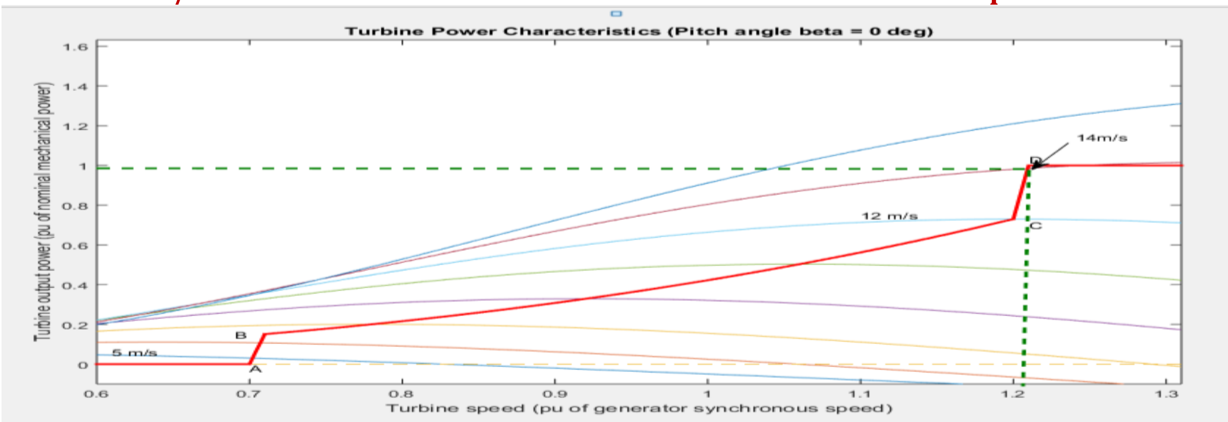

Fig.4.Optimal Power Speed Curve

Fig. 5-13 show the simulation results, in the order as we move from the wind turbine side to the grid side. Under normal condition, the voltage at the bus bars on both WT side and grid side are 1 p.u.

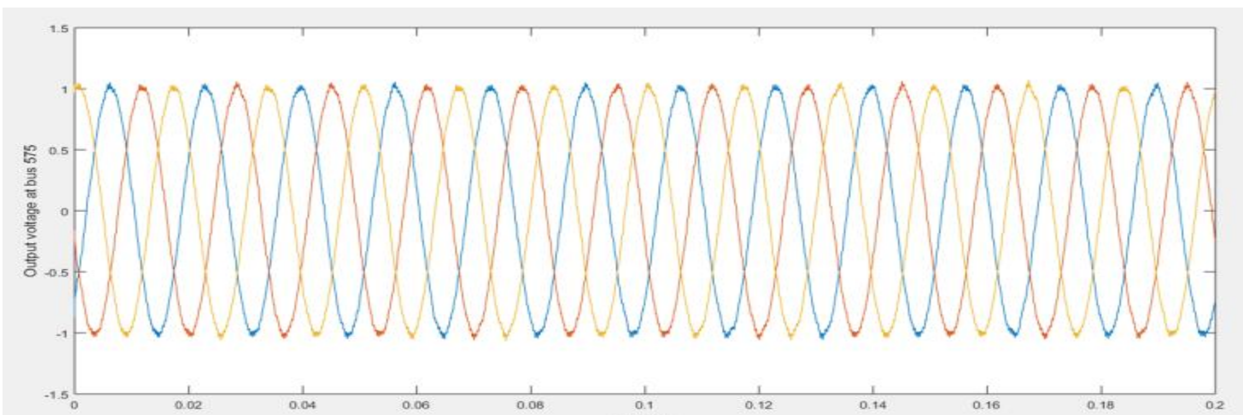

Fig.5. Voltage (V) at busbar connected to WT side

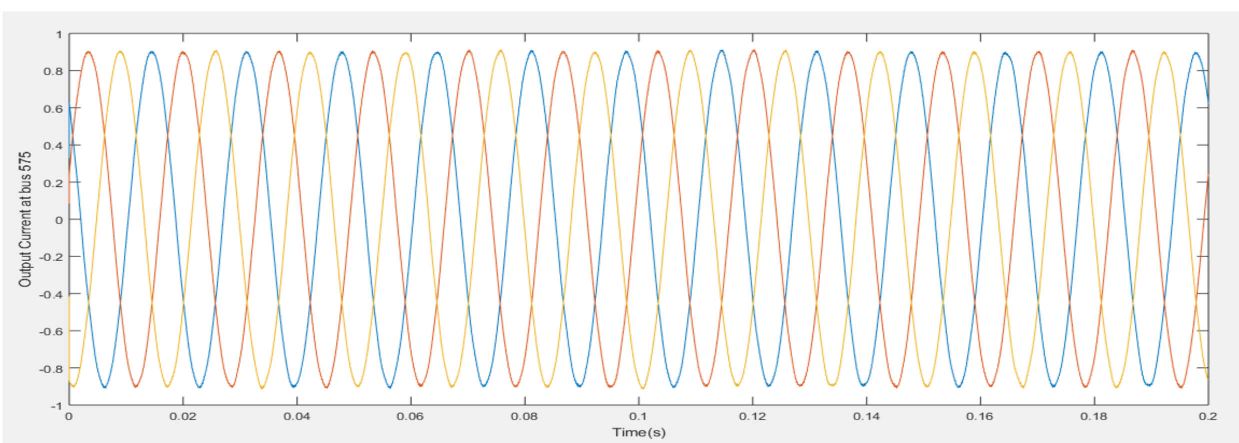

Fig.6.Current (A) at busbar connected to WT side

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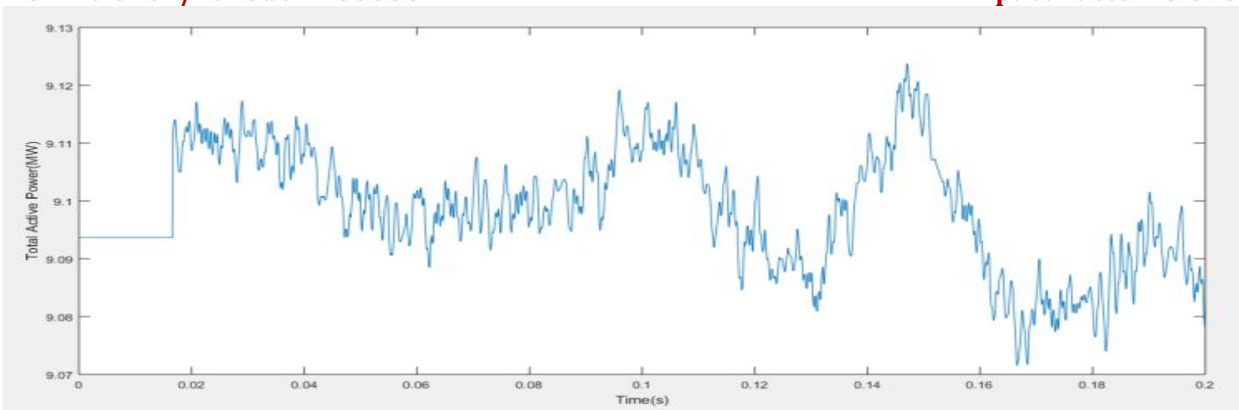

Fig.7.Total Active Power (MW) on grid side

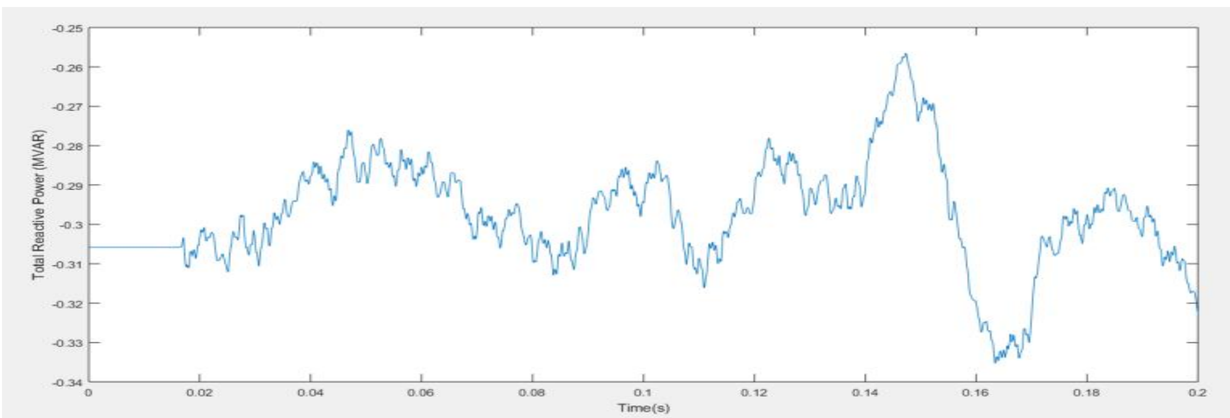

Fig.8.Total Reactive Power (MVAR) on grid side

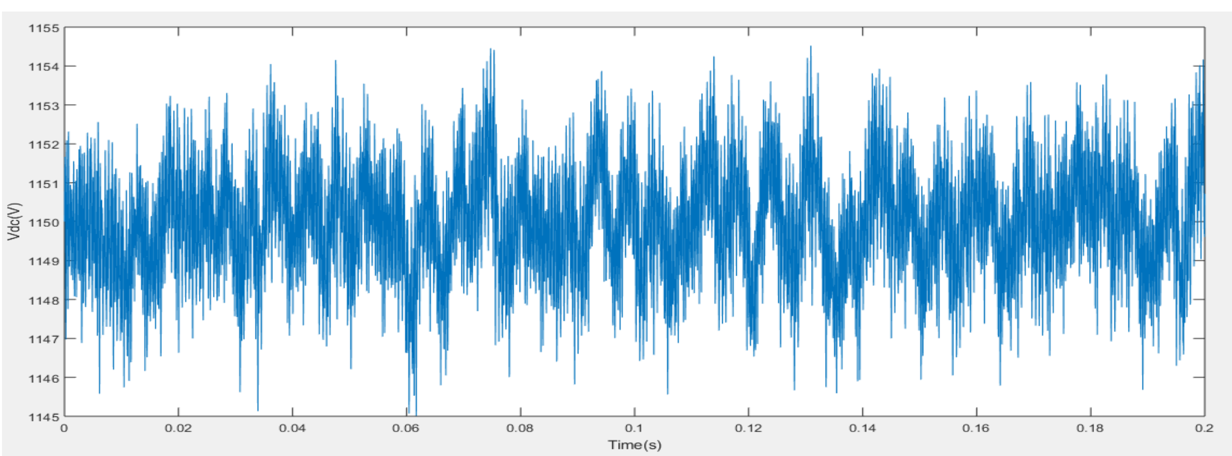

Fig.9.DC Link Voltage (V) between GSC and RSC

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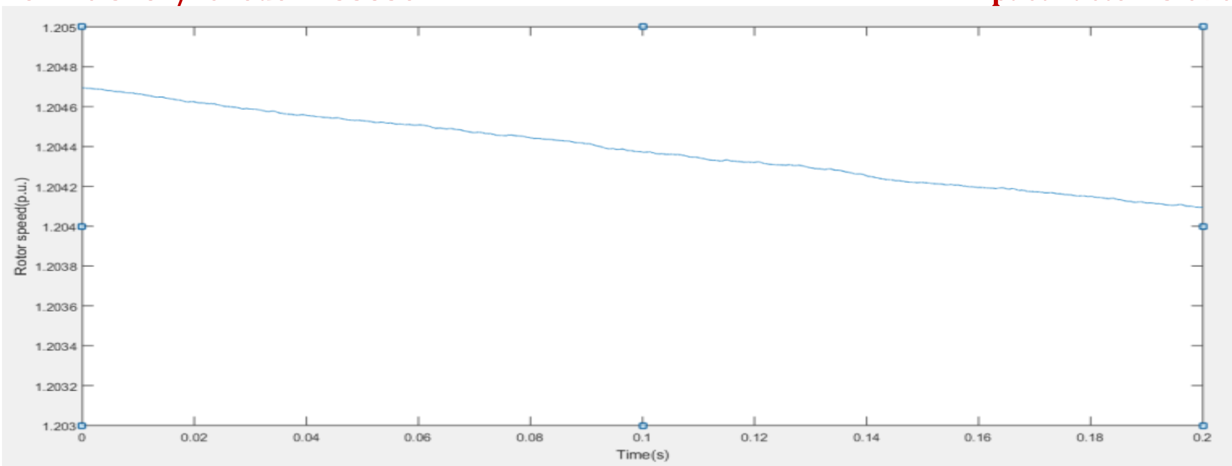

Fig.10.Rotor speed (p.u.)

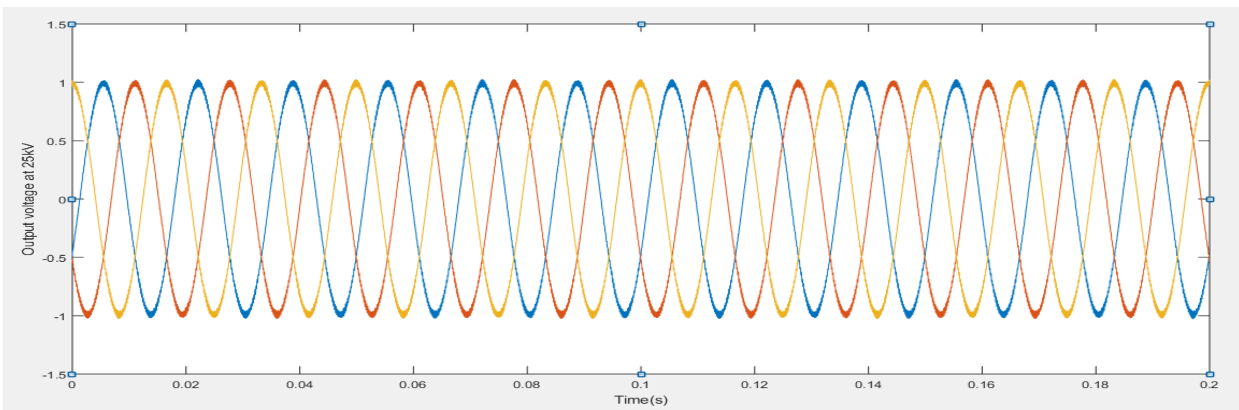

Fig.11.Output voltage (V) at busbar connected to grid

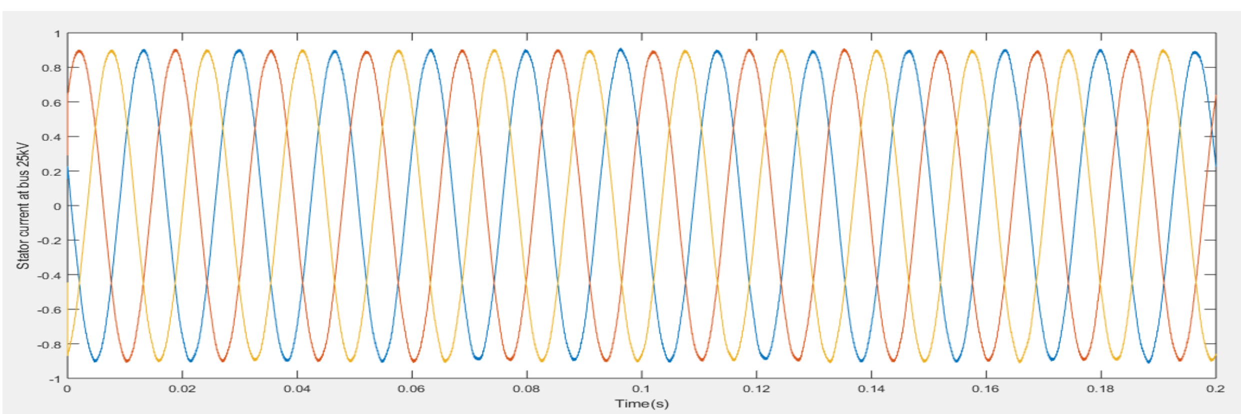

Fig.12.Output current (A) at busbar connected to grid

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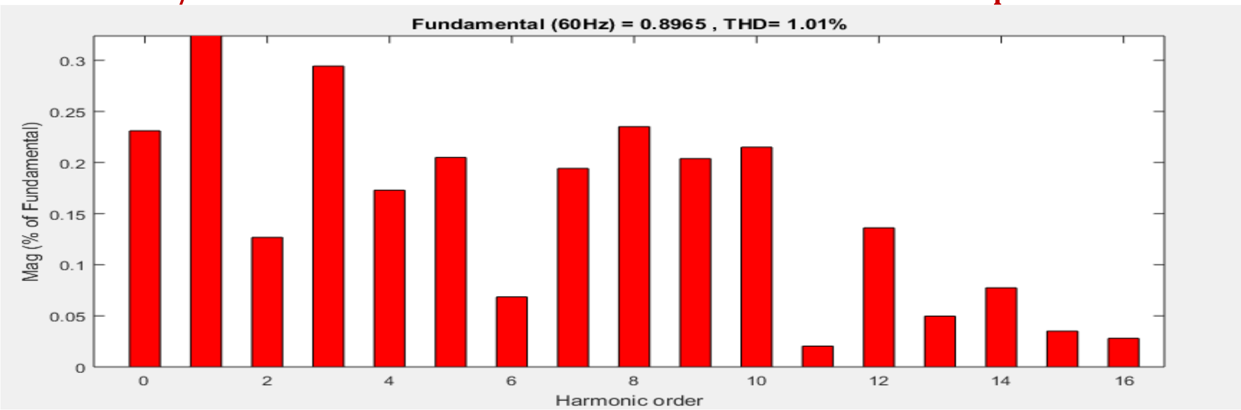

Fig.13. Total Harmonic Distortion in output current (%) on grid side

The FFT analysis done on grid side current gave a THD of 1.01%, which is under the limits prescribed as per IEEE standard 1547.

Under 0.5 p.u. voltage sag condition:
The model is simulated for time 0 < t < 0.2 sec. once again, but this time under 0.5 p.u. voltage sag condition. The assumed fixed wind speed is 14 m/s when the generators rotate at 1.2 p.u. based on the simulated optimal power-speed curve.

Fig.14-22 show the results for simulation under a voltage sag 0.5 p.u. applied at the grid side.

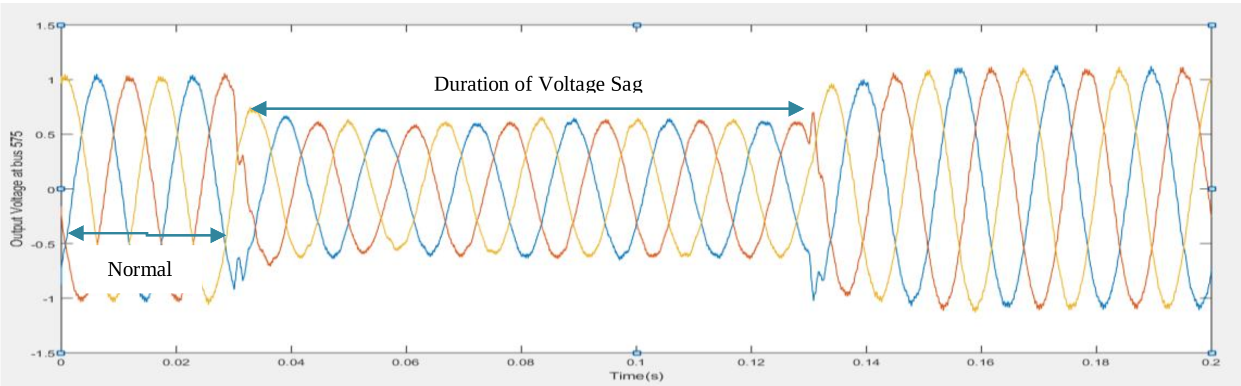

Fig.14. Voltage (V) at busbar connected to WT side

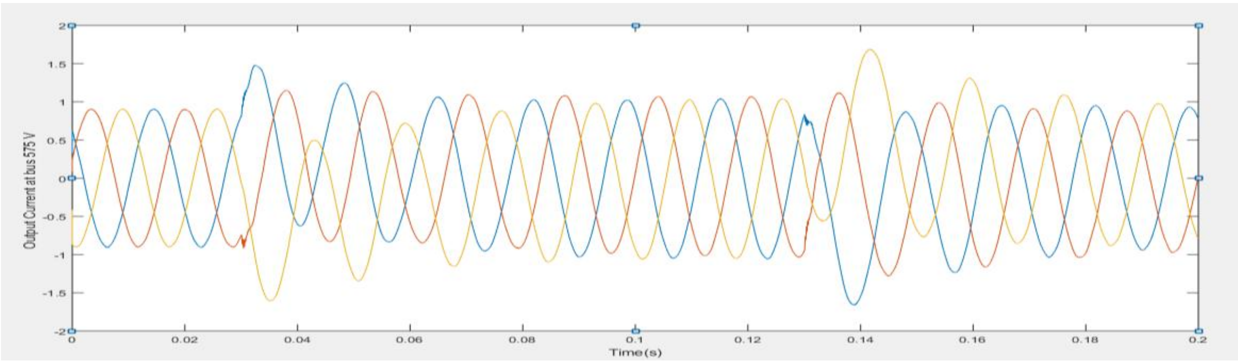

Fig.15.Current (A) at busbar connected to WT side

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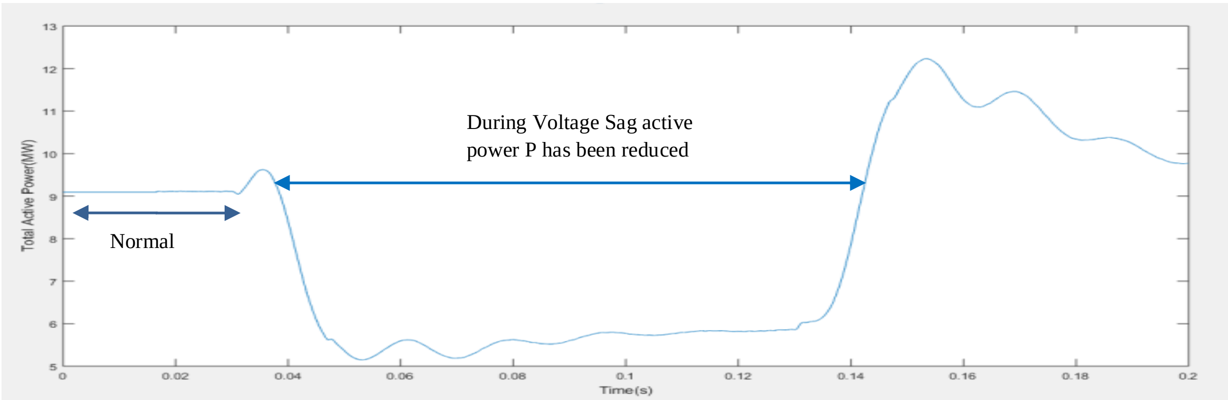

Fig.16. Total Active Power (MW) on grid side

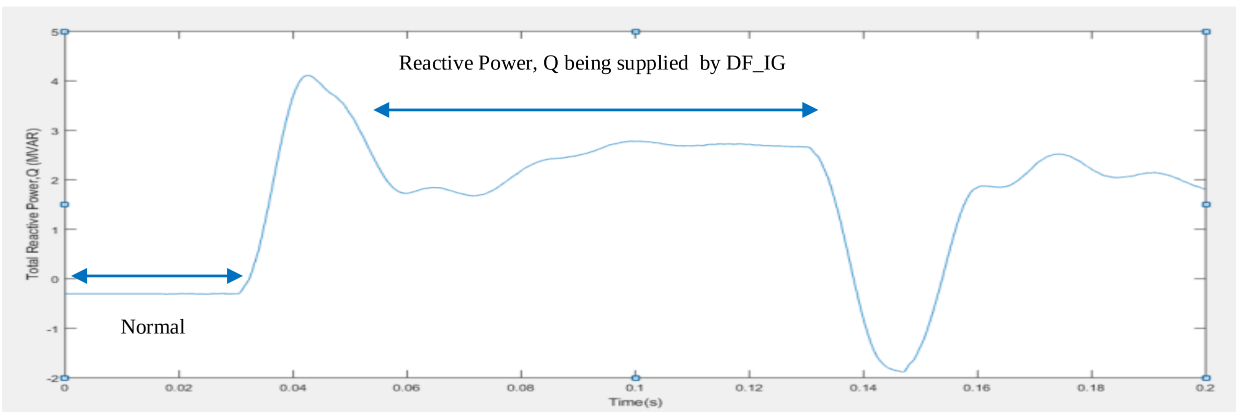

Fig.17. Total Reactive Power (MVAR) on grid side

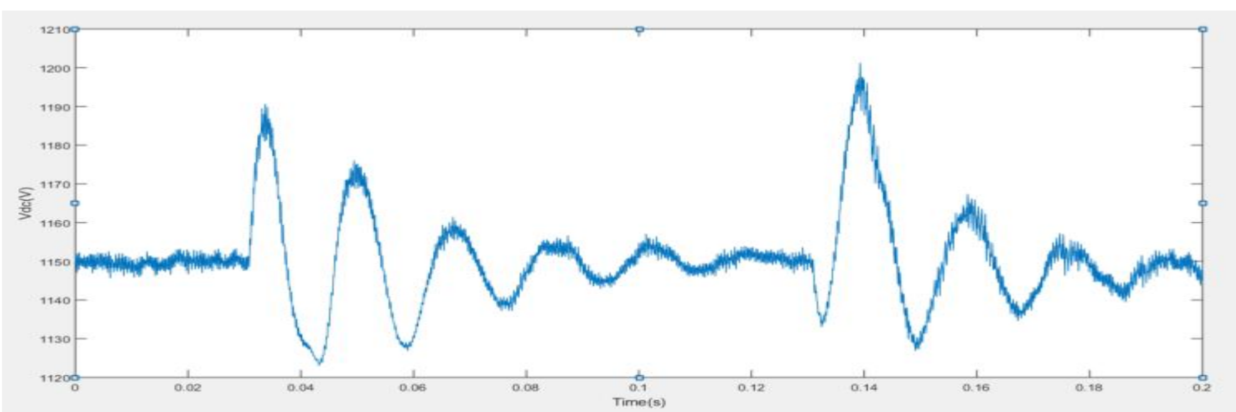

Fig.18. DC Link Voltage (V) between GSC and RSC

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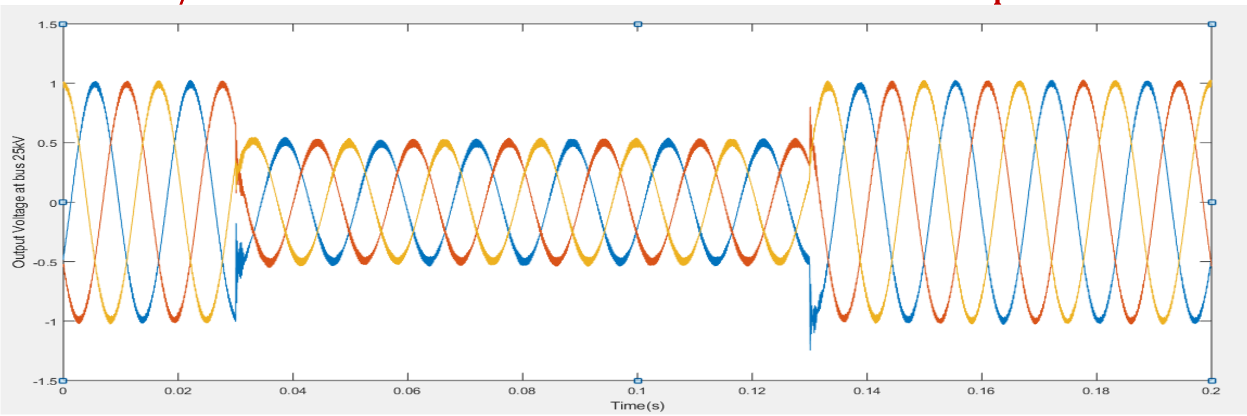

Fig.19. Output voltage (V) at 25kV busbar connected to grid

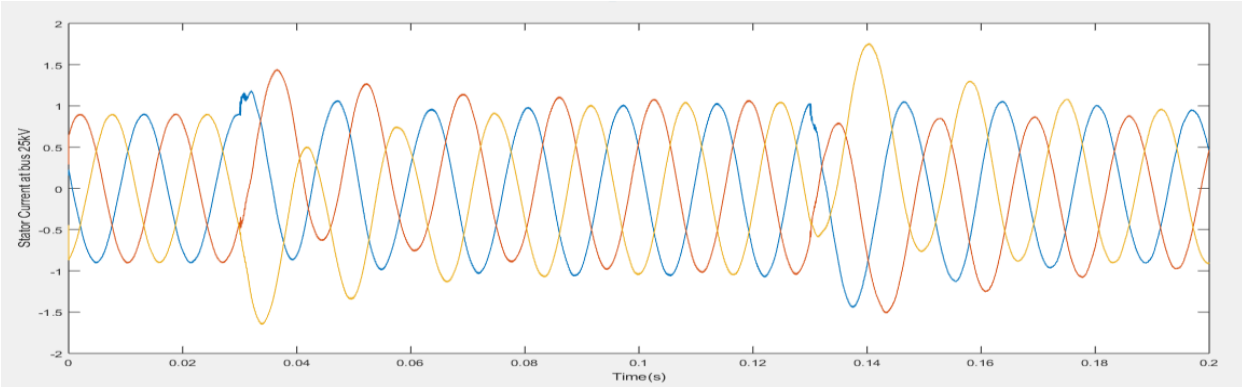

Fig.20.Output current (A) at 25kV bus bar connected to grid

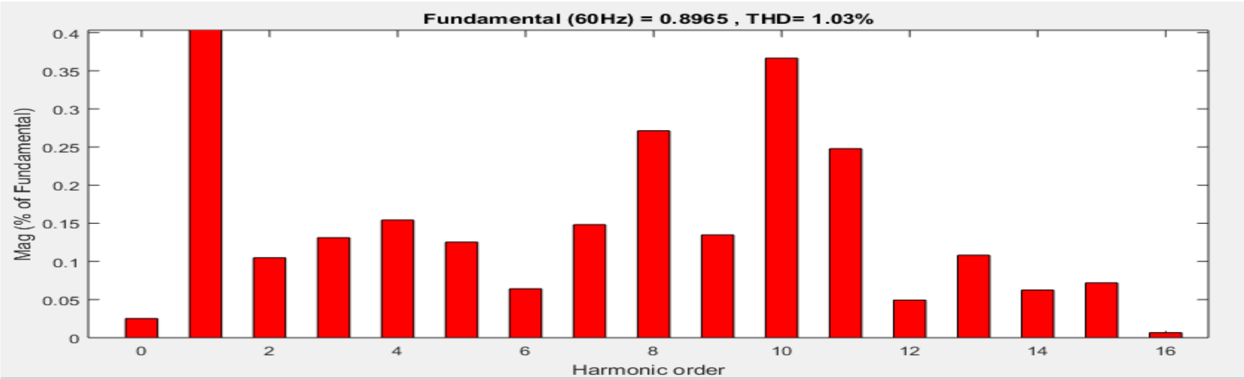

Fig.21. Total Harmonic Distortion in output current (%) on grid side

It is observed that during voltage sag condition, the reactive power requirement increases. This creates a burden on the system to fulfill the reactive power requirement. To reduce this burden rotor side controller plays the main role in such a condition to reduce this burden.

Under normal operating condition, voltages at all the buses were 1 p.u. When voltage sag occurs, the voltage at the buses lower down to 50% of the rated value. Fig.16-17 show, the total active and reactive power, under normal operating condition upto nearly 0.03 sec, were respectively 9 MW and 0 MVArs. During voltage sag condition, the

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active power generated is then converted to MVArs through RSC and is fed to the grid side. Thus, through the RSC the reactive power requirement of the system is fulfilled under the condition of sag.

From power quality point of view, based on the simulation done, it is concluded that on applying voltage sag of 0.5 p.u., THD of 1.03% is obtained, which is still under the limits prescribed as per IEEE standard 1547.

Rotor speed variation

DF_IG is an electromechanical machine, composed of electrical and mechanical equations. The time constant of electrical equations is much lower than that of mechanical equations. Therefore, whenever a change is applied at steady state position, the mechanical time constant will play important role to achieve the stable operating point. During a voltage sag, the electrical quantities change instantaneously, while the mechanical quantities take some time to adapt to the change. Fig.22-23 show the rotor speed variation and corresponding variation of electromagnetic torque with the rotor speed during voltage sag.

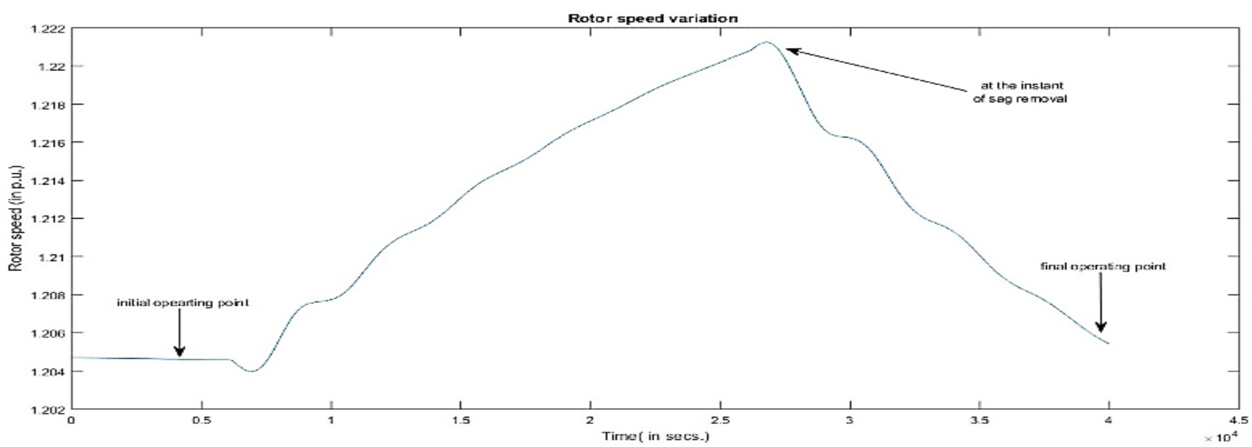

Fig.22.Rotor speed variation under sag

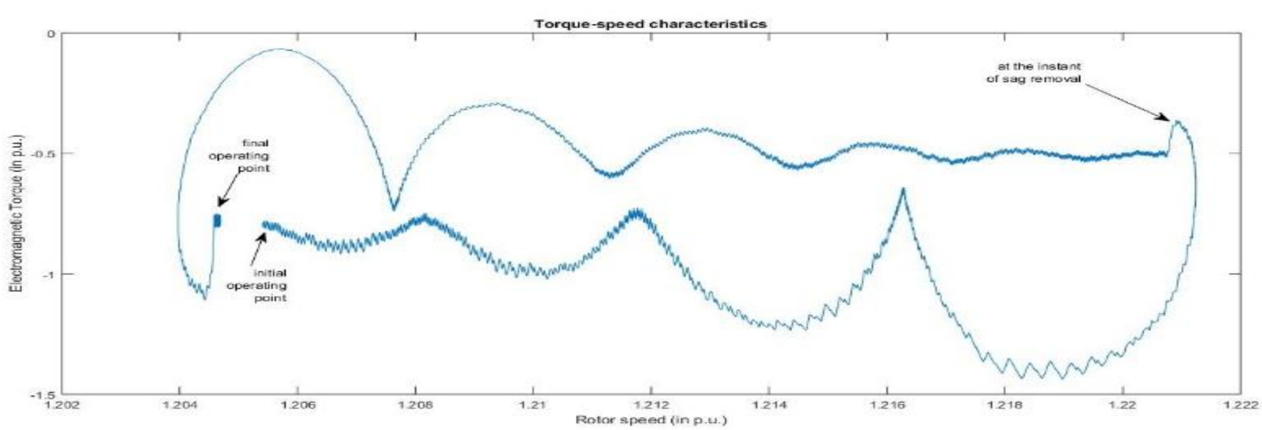

Fig.23.Torque-speed characteristics under sag

V. CONCLUSION

In this work, a direct field-oriented control (FO_C) scheme is implemented on a wind farm of 6x1.5 MW capacity using doubly fed induction generator (DF_IG). The work is done under normal operating condition as well as during the voltage sag condition, which gave improved results in terms of power ripples and THD as obtained through exhaustive simulations done on the developed model (as per IEEE standard 1547).

VI. APPENDIX

System parameters [3]:

- ***Parameters of 10-MVA wind farm composed of six 1.5-MW DF_IG-based WTs:***
  V_{base}=575 V; S_{base}=10 MVA; f_{base}=60 Hz; w_s=1 p.u.;
  w_b =2pif_b=377 rad/s; R_s=0.023 p.u.; R_r=0.016 p.u.;
  L_s=0.18 p.u.; L_r=0.16 p.u; L_m=2:9 p.u.

- ***Transmission line parameters:***
  Length: 30 km
  +ve& zero seq. resistances=0.1153, 0:413 ohm/km
  +ve& zero seq. inductances=1.05, 3.32 mH/km
  +ve& zero seq. capacitances=11.33, 5.01 nF/km

- ***Transformer parameters:***
  T1:12MVA, 575V/25KV, impedance=0.0017 + j0.05 p.u.
  T2: 47 MVA,25 KV/120 KV, impedance=0.00534 +j 0.16 p.u.

- ***Network impedance:*** **R_e+ jX_e=0.0004+j0.004p.u**

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