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Power Quality Improvement by using STATCOM for DFIG based Wind Energy Conversion System

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Abstract- Power quality is a major issue in WECS employing induction generators. Fluctuations in voltage profile and frequency are severe issues due to variations in likely conditions such as wind speed and load variation. In this research, during grid fault, sudden transients and variable wind speed, a comprehensive study of DFIG based wind farm employing self-frequency converters and along with STATCOM is presented. Furthermore, various PQ issues like voltage sag, current harmonics are investigated and such issues are suppressed by employing STATCOM for grid connected WECS. A FLC based strategy is employed to enhance the performance of STATCOM that reduce the disadvantages of employing fixed gains in PI and fuzzy logic controller. By inspecting the simulation results and controller presentations, we have found that the presented technique improves the PQ by mitigating both the voltage sag and current harmonics efficiently and with a better reliability.

Keywords- Power Quality Enhancement, Fuzzy logic Controller, Grid side converter, Rotor side converter, PI Controller, STATCOM, Doubly Fed Induction Generator (DFIG).

I. Introduction

In the present time, the sources like solar, wind, hydro and tidal energies are majorly used as renewable sources and use of these sources is growing rapidly due to less cost, clean and sustainable [1-2]. In early time the wind farms were installed with constant speed induction generators and turbines [3- 4], but due to fixed speed of these, the power efficiency is very low because wind speed changes whole day. These days, the use intelligent wind generators with a changeable speed are increased sufficiently for enhancing the efficiency. That's why the DFIGs are employing a lot because of their variable speed working, better control of reactive

and active power and using moderately rated power converter [5] [6]. The power quality is serious issue; variations have a negative effect on stability and PQ [7]. Furthermore, the grid connected wind farms have flickers, voltage sag and current harmonics etc. Due to the PQ problems, automatic reset, data errors and damage of equipment are more severe. The sag in voltages is main issue which arises because of 3 L-G fault or by running big motors and it can cause sudden tripping of equipment, mal-operation and shutdown of system [8]. [9].

II. Doubly Fed Induction Generator (DFIG)

A DFIG system has an AC/DC- DC/AC, IGBT dependent PWM converter and a wound rotor induction generator as shown in figure 1.[10] In DFIG system, there is an utmost extraction of energy with the minimum wind speeds by improving turbine speeds and reducing mechanical pressures. The DFIGs have some more benefits like generating or absorbing reactive power by power electronic converter and it reduces the requirement of capacitor banks in presence of squirrel cage induction generator.[11]

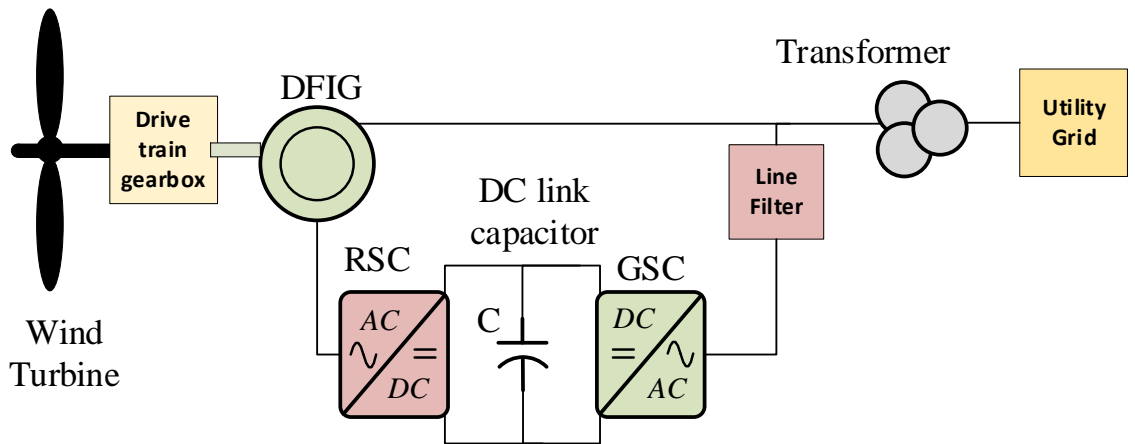


Fig.1. Grid connected DFIG based wind power system

III. DFIG Modelling and Control

The modelling of DFIG is shown in Fig. 1. Controlling of the DFIG is done in a rotating d-q reference frame, along d-axis aligned by the stator flux vector which is presented in Fig.2. The control of stator reactive and active powers is done by changing the voltage and current of the rotor. Hence, current and voltage of rotor require to be decomposed within the stator reactive and active power.[12]

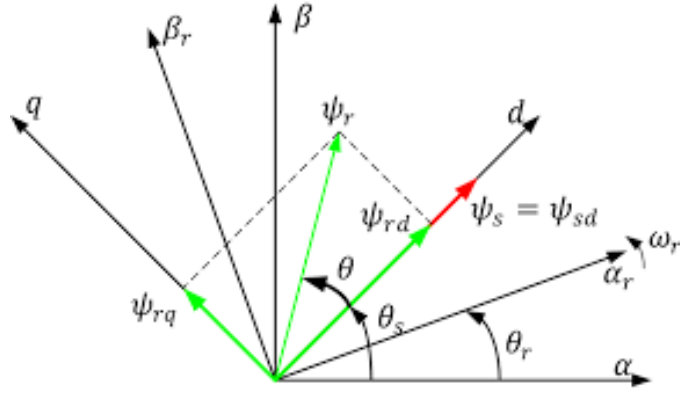


Fig 2. Vector presentation of stator flux -familiarized control

A. Dynamic Modelling

The stator's electrical and mechanical power output can be calculated as:

$$P_t = T_k * w_t \quad (1)$$

$$P_z = T_{qk} * w_z \quad (2)$$

For a loss less generator the mechanical equation is:

$$\frac{Jd_{w_t}}{dt} = T_k - T_{qk} \quad (3)$$

In steady-state at fixed speed for a loss less generator

$$T_k = T_{qk} \text{ and } P_k = P_z + P_t \quad (4)$$

$$P_t = P_k - P_z = T_k w_t - T_{qk} w_z = -sP_z \quad (5)$$

Here's is the generator slip, which is usually much less than 1 and so, P_z is only a small part of P_s .

1. Voltage equations:

a. Stator Voltage Equations

$$V_{qs} = p\lambda_{qs} + w\lambda_{qs} + r_s i_{qs} \quad (6)$$

$$V_{ds} = p\lambda_{ds} - w\lambda_{qs} + r_s i_{qs} \quad (7)$$

b. Rotor voltage Equations

$$V_{qr} = p\lambda_{qr} + (\omega - \omega_r)\lambda_{ds} + r_s i_{qr} \quad (8)$$

$$V_{dr} = p\lambda_{dr} - (\omega - \omega_r)\lambda_{qr} + r_s i_{dr} \quad (9)$$

c. Power Equations

$$P_s = \frac{3}{2} (V_{ds} I_{ds} + V_{qs} I_{qs}) \quad (10)$$

$$Q_s = \frac{3}{2} (V_{qs} I_{ds} - V_{ds} I_{qs}) \quad (11)$$

d. Torque Equation

$$T_g = -3 \frac{p}{4} (V_{ds} I_{qs} - V_{qs} I_{ds}) \quad (12)$$

2. Flux Linkage Equations:

a. Stator Flux Equations

$$\lambda_{qs} = (L_{is} + L_m)i_{qs} + L_m I_{qr} \quad (13)$$

$$\lambda_{ds} = (L_{is} + L_m)i_{ds} + L_m I_{dr} \quad (14)$$

Rotor Flux Equation:

$$\lambda_{qr} = (L_{ir} + L_m)i_{qr} + L_m I_{qs} \quad (15)$$

$$\lambda_{dr} = (L_{ir} + L_m)i_{dr} + L_m I_{ds} \quad (16)$$

In wind generation, A quantity of the accessible power is converted to mechanical power into by the rotor blades working on the wind turbines rotor shaft.[13] For computation of mechanical power's steady-state from a wind turbine, the supposed $C_p(\lambda, \beta)$ curve may be employed. Fig. 3 shown that power coefficient and tip speed ratio curves.

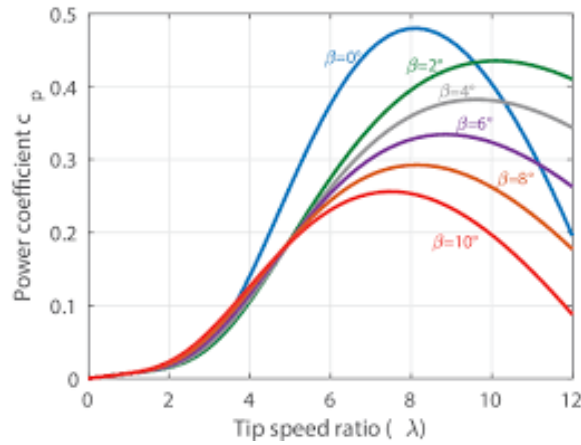


Fig. 3 C_p (power coefficient) v/s tip speed ratio, λ

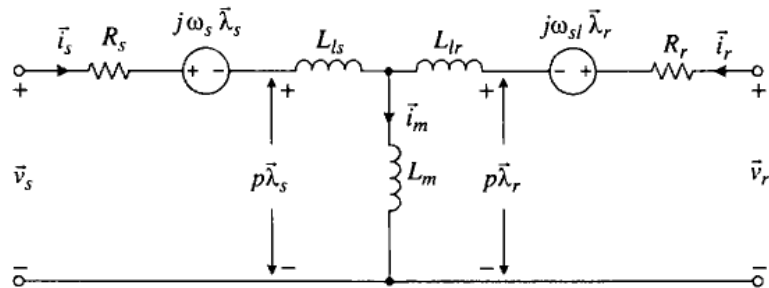


Fig. 4 Equivalent circuit of DFIG [6]

Fig.4 presents DFIG d-q equivalent circuit. The voltages, currents and fluxes may be presented as with stator flux-oriented control, [14]

$$\lambda_{dqs} = L_s i_{dqs} + L_{pq} i_{dqr} \quad (17)$$

$$\lambda_{dqr} = L_r i_{dqr} + L_m i_{dqs} \quad (18)$$

$$v_{dqr} = R_s i_{dqs} + \frac{d}{dt} \lambda_{dqt} + j\omega_e \lambda_{dqt} \quad (19)$$

$$V_{dqr} = R_r i_{dqr} + \frac{d}{dt} \lambda_{dqr} + j(\omega_e - \omega_r) \lambda_{dqr} \quad (20)$$

Here: L_m - (Magnetizing Inductance)

L_s - (Stator self- Inductance)

L_r - (Rotor self- Inductance)

λ_{dq_s} - (Stator d-q axis flux linkage)

λ_{dqr} - (Rotor d-q axis flux linkage)

i_{dqr}, i_{dq_s} - (Stator and Rotor d-q axis current)

Stator flux vector phase angle can be computed as;

$$\lambda_{dq_s}^s = \int (v_{dq_s}^s - R_s i_{dq_s}^s) dt \quad (21)$$

$$\theta_e = \tan^{-1} \frac{\lambda_{dq_s}^s}{\lambda_{ds}^s} \quad (22)$$

Here the superscript 's' represents quantities within stationary reference frame.

IV. STATCOM

STATCOMs are of two types which are voltage source converter (VSC) and current source converter (CSC). Usually, the CSC methodology is less effective than VSC that's why VSCs are employed in STATCOM. In large capacity wind farms, larger voltage rating is preferable, hence this research uses voltage source STATCOM like a dynamic reactive power compensator. [15-17] The basic for VSC-STATCOM linked with an ac source is presented in Fig.5, In which V_s indicates the ac voltage source, V_{si} indicates controlled ac output voltage of STATCOM, and interfacing resistance and reactance as R_s and X_s .

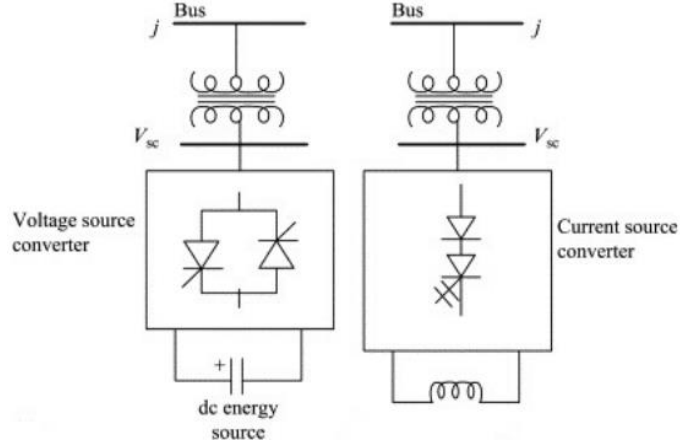


Fig 5. STATCOM Model

Here we are supposing that power transmission's positive path from the grid to STATCOM, if $X_s \gg R_s$, the active power P and reactive power Q to the STATCOM equation (23) and (24) evidently presents that the active power P and reactive power Q may be forced by varying the output voltage V_{si} and the phase difference α between V_s and V_{si} .

$$P = \frac{V_s V_{si}^i \sin \alpha}{X_s} \quad (23)$$

$$Q = \frac{V_s^i (V_s \cos \alpha - V_{si}^i)}{X_s} \quad (24)$$

The direction of active power can be obtained by polarity of α , and reactive power direction may be obtained by amplitude subtraction of V_s and V_{si} .

V. Power Quality Improvement

A good power quality enhances the system operation efficiency while poor power quality may harm the equipment operation and further the whole power system. A poor power quality has various issues like voltage fluctuation, voltage sag & swell, long term voltage interruption, noise, waveform distortion, power frequency variations, harmonics, voltage spike, transient and flicker that causes power quality problems & can be traced to a specific type of electrical disturbance. Out of referenced issues the problem of power ripple has become most severe issue in advancement of wind generation system because such ripple results a poor power quality that affects the system reliability and leads to malfunctioning of the system. The various power quality problems show in Fig 6.

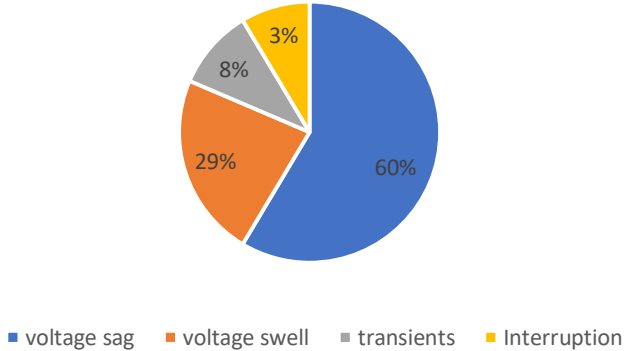


Fig 6. Power quality problems

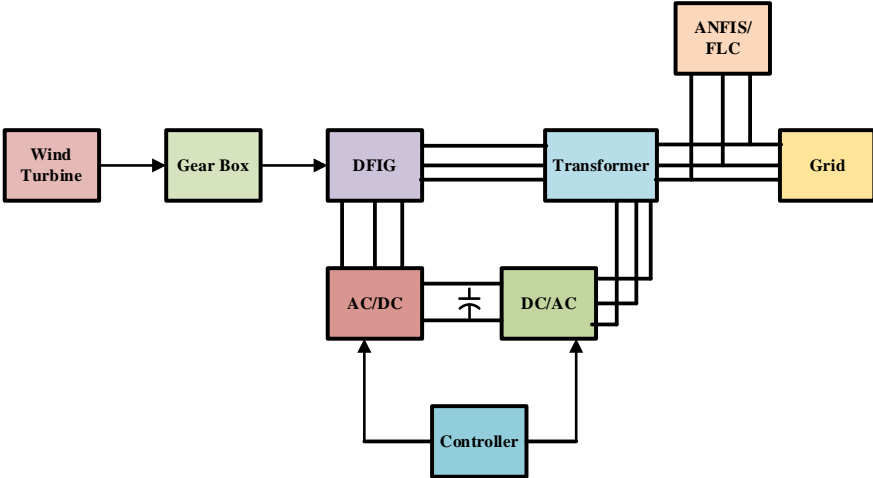


Fig. 7 Power quality Improvement of controller-based wind energy conversion system

The block diagram shown in Fig.7 proposed an intelligent controller-based wind energy conversion system which consists of two back-to-back converters. The neural network, fuzzy logic and neuro-fuzzy controllers are one of the forms of artificial intelligence techniques that can be applied for controlling of these two converters. Further, the use of fast reactive power compensators can improve the power system stability and hence maximum power transfers through the electric system. An intelligent method of control strategy using PI controller and neuro fuzzy system may be used in order to achieve smooth grid integration, energy savings, reactive power compensation and effective real power flow.

VI. Control Strategy

We are employing an intelligent controlling strategy for improving the performance of STATCOM with FLC. The advantage over conventional controller is, FLC can be used without any mathematical modelling.[16] Furthermore, FLC is more efficient to handle nonlinearity and is further vigorous in comparison of conventional PI controller that too enhances the efficiency of STATCOM. The employed control technique is presented below.

A. Conventional PI Controller

Here, the controlling of STATCOM is done by conventional PI controller as presented in Fig.8. We assumed gain values P and I as $K_P=0.1$ and $K_I=2$ with trial and error technique. The sag voltage is evaluated with reference voltage and the error is evaluated with PI controller and then, output is renovated to 3 phases via unit vector generation, further, it is given to PWM generator to offer gate pulses to series so that it can capable to insert the needed voltage for the reduction of voltage sag.[17]

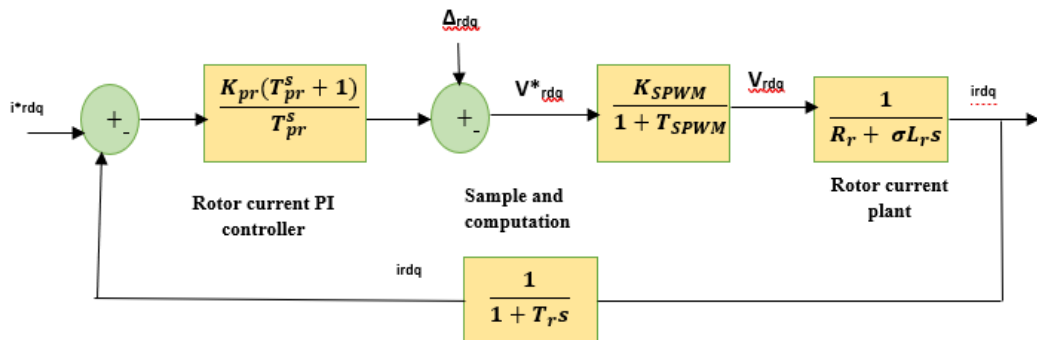


Fig.8 Conventional Pi Controller

B. Fuzzy Logic Controller

The use of FLC is best over other operations of fuzzy set theory; the major advantage is that it utilizes linguistic variables over numerical variables. It uses human potential to understand the system's behavior and hence, built up on quality control system. It employs basic method to reach at a certain end depend on indistinct, indefinite, unclear, noisy, or absent input data. [18-20] The FLC in simplified way is shown as in Fig.9.

- The input data is altered into suitable linguistics by a fuzzification interface.
- The study of data base within the necessary linguistic descriptions and control law set is done with knowledge base.
- The collection of fuzzy control act from the data of the control rules and the linguistic variable explanations is done by a Decision-Making Logic.
- A Defuzzification interface that surrenders a non-fuzzy control act from an inferred fuzzy control act.

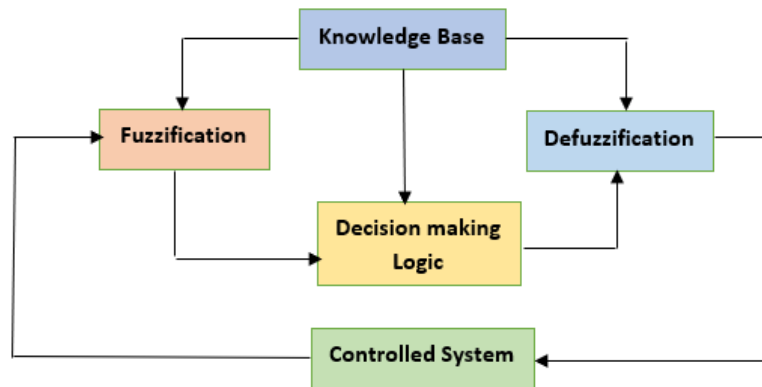


Fig.9 Fuzzy Logic controller

VII. Simulation Model

In the presented model wind turbines of 9 MW capacities are employed, which utilizes the DFIGs. The wind turbines are simulated with grid of 50Hz and rotors are simulated to the 50 Hz grid and the rotors are obsessed by a changeable-pitch wind turbine. Usually, the DFIG speed kept somewhat more than synchronous speed for generating the power. The variation in speed occurs around 1pu at condition of no load and in full load 1.006. There is also a protection system to monitor the speed, voltage and current. The remaining reactive power needed for maintaining the bus voltage near 1pu by a 10-Mvar STATCOM. The mechanical power (turbine speed) is presented for wind speeds range from 5 m/s to 13 m/s. The

investigation on transient stability is done by wind turbine model and the STATCOM model along large simulation times.

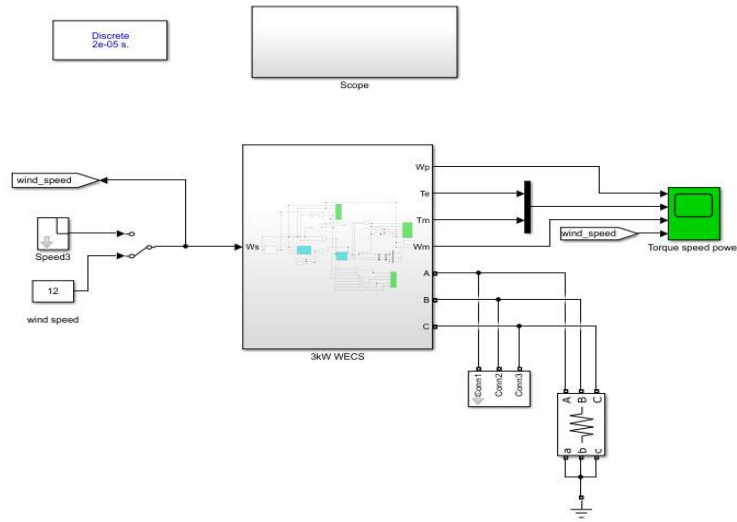


Fig. 10 Wind Turbine Model

VIII. Simulation Results

To confirm the achievability of the planned control scheme, MATLAB simulations were done. In the study, the employed DFIG is of 2MW capacity and the wind speed is steady at 10m/s. To create the unbalancing condition in voltage the value of phase-a voltage was reduced by 20%. In starting, the system was running in balanced conditions, after 1.5s the grid voltage was varied and further, the balanced condition was achieved in 3s. The grid current and voltage with no compensation are presented in Fig. 11(a) (b) Here are major ripple factors in the rotor torque, speed, stator reactive and active power as presented in Fig. (12) (13).

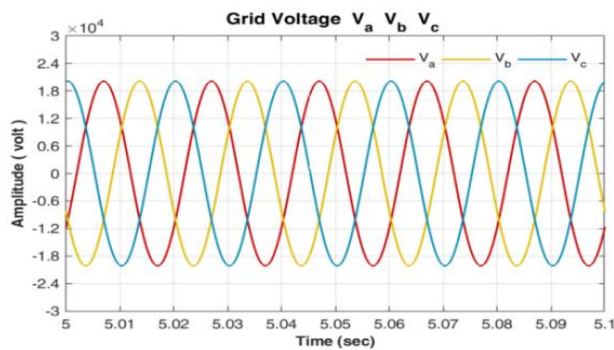


Fig.11 (a) Grid Current

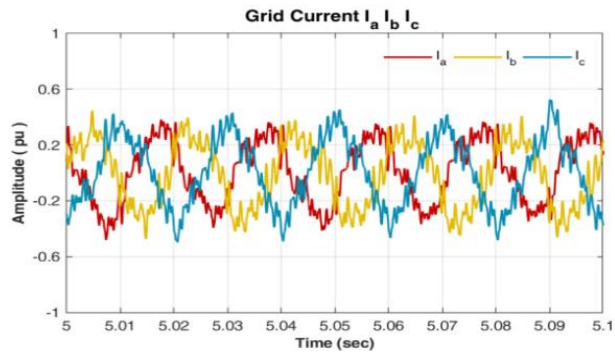


Fig.11 (b) Grid voltage

The fault happens at 0.2 sec, voltage sag appears about 30%, at this moment reactive power produced by STATCOM is -0.27 pu, whereas there is about to zero power in conventional circuit. Further, the peak capacitive power produced by a STATCOM reduces linearly along voltage reduces (constant current). Availing enhanced power in fault condition is main benefit of the STATCOM.

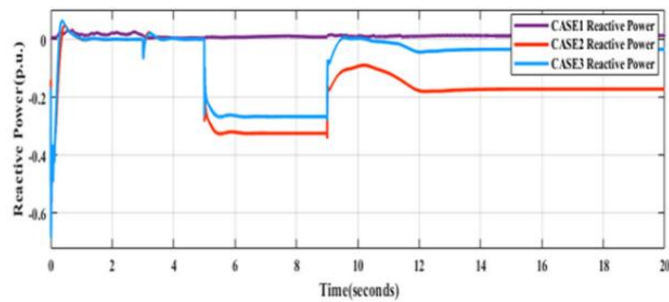


Fig. 12 (a) Active power performance

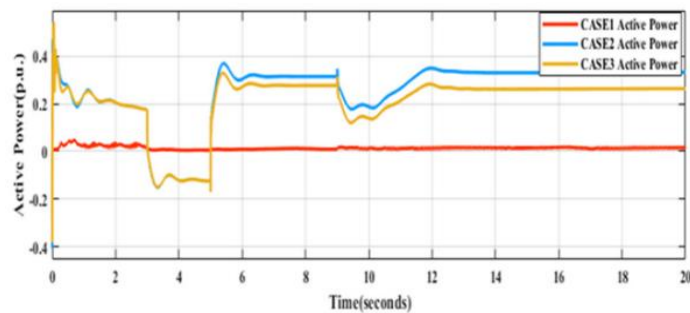


Fig. 12 (b) Reactive power performance

There is severe pressure on generator shaft and gearbox due to fluctuations in torque and rotor speeds. For mitigating the above referenced issue, the reactive power ripple control technique is employed.

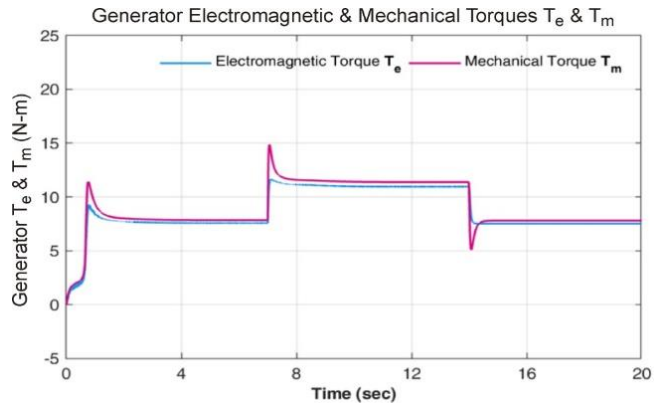


Fig. 13 (a) Generator Torque

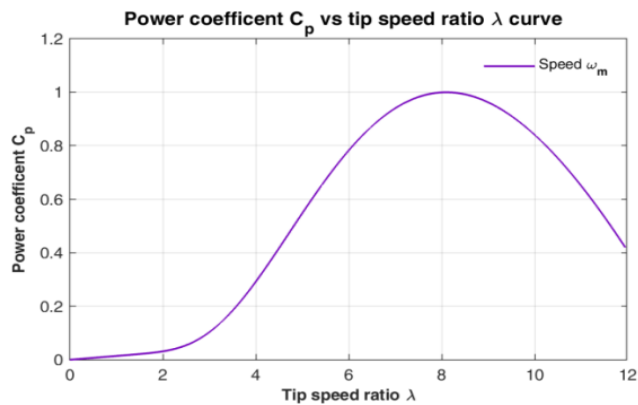


Fig. 13 (b) Constant & Impulsive Wind speed condition

IX. Conclusion

In this research the technique for enhancement of voltage and current quality are presented for grid linked DFIG network. Several PQ issues like sag in voltage and current harmonics are investigated in MATLAB environment. The FLC based STATCOM is presented as a solution for PQ improvement and the results are also evaluated for conventional PI and FLC based controller. By investing, we can conclude that the conventional controller is capable to reduce voltage sag but not the load current harmonics efficiently while the presented FLC based STATCOM controller reduces the voltage sag and along with load current harmonics efficiently by maintaining the THD in standard limits. Hence, the FLC based controller was proved efficient for enhancing PQ in a grid connected wind power network.

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