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Research Article

A New Reference Signal Generation and DC-link Control for Fault Mitigation and Power Quality Improvement of DFIG

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Abstract: This study delivers a new approach for reference signal generation to improve the power quality problem of Doubly Fed Induction Generator (DFIG). DFIG consists of RSC (Rotor Side Converter) and GSC (Grid Side Converter) and common DC-Link. RSC converter used to mitigate the sag and swell compensation by enhanced phase lock loop and variable speed Limit. The aim of GSC is to mitigate the current harmonics and load balancing control by non-linear adaptive filter approach. The 60% of DC-Link voltage control obtained by GSC and remaining 40% of sag is controlled by the external chopper through the DC-Link voltage balancing. Additional chopper is presented to reduce the size, stress of DC-Link capacitor and also it avoids additional control loop in GSC. The system power qualities are verified through simulation studies.

Keywords: Active filtering, DC-link control, DFIG, reference signal generation, sag/swell

INTRODUCTION

The wind power a highly attractive power in the way of growth and due to increasing interest about CO_2 emission. The global installed wind capacity analysis from (1996-2013) report says the maximum capacity of power obtained 45,169 MW. In region wise, Asia has been reached more than 20,000 MW. North America has reached 1500 MW power in 2012. Asia is the largest region in the growth of wind generation (Global Wind Energy Council/GWEC, 2013). The recent power system structure has highly complicated and the power quality improvement in that system is a more challenging aspects based on restriction on transmission line expansion and environmental conditions.

The fundamental concepts of power electronics, including averaged modeling of PWM converters and fundamentals of converter circuits and electronics, control systems, magnetic, low harmonic rectifiers and resonant converters (Erickson and Maksimovic, 2001). The wind power has been attracting investments around the World due to the increasing interest about CO_2 emissions and the searching of renewable energies alternatives. The results of conditions the systems have been highly loaded and power quality disturbances occur. The FACTS devices are Major role to mitigate the power quality disturbances. Power quality disturbances create negative impact on PQ standards. The disturbances are Power frequency deviation, supply voltage variations, flickers, transient voltages and harmonics and so on. Peak values, crest factor, Total Harmonic Distortion (THD), power factor are the traditional indices. Normalized instantaneous distortion energy ratio, instantaneous frequency indices are also included in traditional method. These are all mostly obtained from the signal frequency spectrum (European Standard EN 50160, 2002; Granados-Lieberman *et al*., 2011).

The stability of power system is to develop restoring forces and classification of rotor angle, voltage, frequency of an electric power system can be improved by using power regulation. The dynamic stability can be improved by forcing the excitation of generator (Anderson and Fouad, 2002). The proposed power quality indices are the voltage sag and swell. The voltage sag will appear in the power system network with respect continuous unbalanced short circuit problem (Figueroa *et al*., 2013).

The inductance or capacitance variation in the charge level causes swells (Hingorani, 1995). The sag and swell are the major impact on the power quality problems in the system stability and its performance (Khadkikar and Chandra, 2011). The dynamic stability can be improved by forcing the excitation of th e generators. Sag and swell has been controlled by applying variable speed limits of wind generator.

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Generally variable speed has many advantages than constant speed generator (Zadehbagheri *et al*., 2013).

To extraction of harmonics, instantaneous symmetrical components and reactive current of nonlinear system by using enhanced phase locked loop (Karimi-Ghartemani *et al*., 2005). Power quality has been maintained when fault occur on grid fault condition the DFIG are disconnected from the grid to save the wind generator. During the disconnection of grid, the enhancement of current and disturbance occurs on rotor side causes the induction generator damages. The many of traditional topologies suffer from disconnections problem of grid. Recently the active filtering and some of FACTS devices are used to mitigate the Faults during the disturbance conditions (Branda *et al*., 2011).

The novel control approach based on enhanced phase-locked loop and a nonlinear adaptive filter for reference signals generation is derived and analyzed dynamically for shunt and series converters (Teke *et al*., 2011). The RSC controller has phase locked loop reference signal generation and adaptive reference signal generation methods are presented to mitigate the current and voltage variation and flickering problems in proposed system topology. The DC-Link capacitor voltage control has an impact of sag as well as swell compensation and also real and reactive power control and it is controlled by variable speed limits.

DC-Link capacitor voltage control has been obtained by getting active power support to mitigate the faults and reactive power control (Liserre *et al*., 2005). The Proposed scheme has buck boost converter is provided the active power support to DC-Link capacitor. This converter is control the sag and swells operation by buck and boost operation. To avoids external and complicated additional loops for GSC side converter by using chopper topology. The design of LCL filters and back-to-back converter control helps to each other to improve the power quality and sag/swell mitigation.

MATERIALS AND METHODS

The power circuit configuration of DFIG: The overall configuration of a DFIG system proposed shown in Fig. 1a. The Y connected LCL filters and delta connected LCL filters for GSC and RSC, respectively. The Present 6 KW with 690 V DFIG, RSC connected with series to DFIG and GSC connected parallel with grid or DFIG stator. Common DC-Link capacitor is connected with Buck-Boost converter. Equivalent circuit for LCL filters is shown in Fig. 1b.

Rotor Side Converter (RSC) control: The reference voltage generation of rotor side controller has derived from the both schemes of improving the PLL and Non-linear adaptive filters (Karimi-Ghartemani *et al*., 2005). The present strategy used to minimizes the complexity in parameters tuning. The measurement of supply voltage is necessary for rotor side controller.

The measurement of input signal $A(t)$ is estimated by following. $B(t)$, difference of input and synchronized components. $C(t)$, is amplitude of $D(t)$. $D(t)$, Is fundamental input components. $E(t)$, PLL signals. $\theta(t)$, a phase angle $D(t)$.

$A(t)$, corresponding to supply voltage V_{abc} and $E(t)$ is obtained from V_{PLL} shown in Fig. 2 and 3. The required signal for compensation is obtained from (V_{PLL}-V_{abc}). The fundamental input components $D(t)$ are derived from (Teke *et al*., 2011) is given by:

$$D(t) = C(t)\sin\frac{C(t)}{K_2} + pt \tag{1}$$

The control circuit shown in Fig. 2 and 3 used to extract the signal components. The low pass filter (100 to 150 Hz) used to extract the positive and negative sequence components with different time delay interval. Positive sequence is usually obtained from normal conditions and negative sequence is generated by load unbalanced conditions. The $C(t)$ is signal variation directly proportional to supply voltage V_{abc} variation. The presented control loop is effectively control and mitigates the real/reactive power disturbance by controlling the voltage and current.

DC-link control of buck-boost converter: The proposed model of Bidirectional DC-DC converter is shown in Fig. 4. The converter operates in discharging mode (boost mode), it provides supporting waveform for active/reactive power mitigation and it has an ability to absorb the reactive power. The converter act in buck mode while capacitor is discharging. In discharging modes the DC-Link capacitor are more stable compared with conventional DC-Link control methods.

The average current mode controller used in the proposed buck-boost chopper. The charging and discharging of buck boost converter by the expression (2) basis is derived to control the sag and swell faults by maintain the constant DC-Link voltage is bellow (Erickson and Maksimovic, 2001):

$$G_{id}(s) = V_{at}\frac{C+\frac{2}{R}}{s^2LC+s\frac{L}{R}+(1-D^2)} \tag{2}$$

$$G_{vi}(s) = \frac{(1-D)1-\frac{sL}{R(1-D)^2}}{C+\frac{2}{R}} \tag{3}$$

The Grid Side Converter (GSC) control: In the RSC converter $A(t)$ obtained from I_A, $B(t)$ is obtained from I_{error}. The measurement of load current I_L, injected current I_{inj} and DC-Link capacitor voltage V_{DC}. Compared reference signal is applied through PI controller. Carrier based PWM is generated for RSC.

Design of LCL filter for GSC and RSC: The filter design aspects enable a little change to the rotating

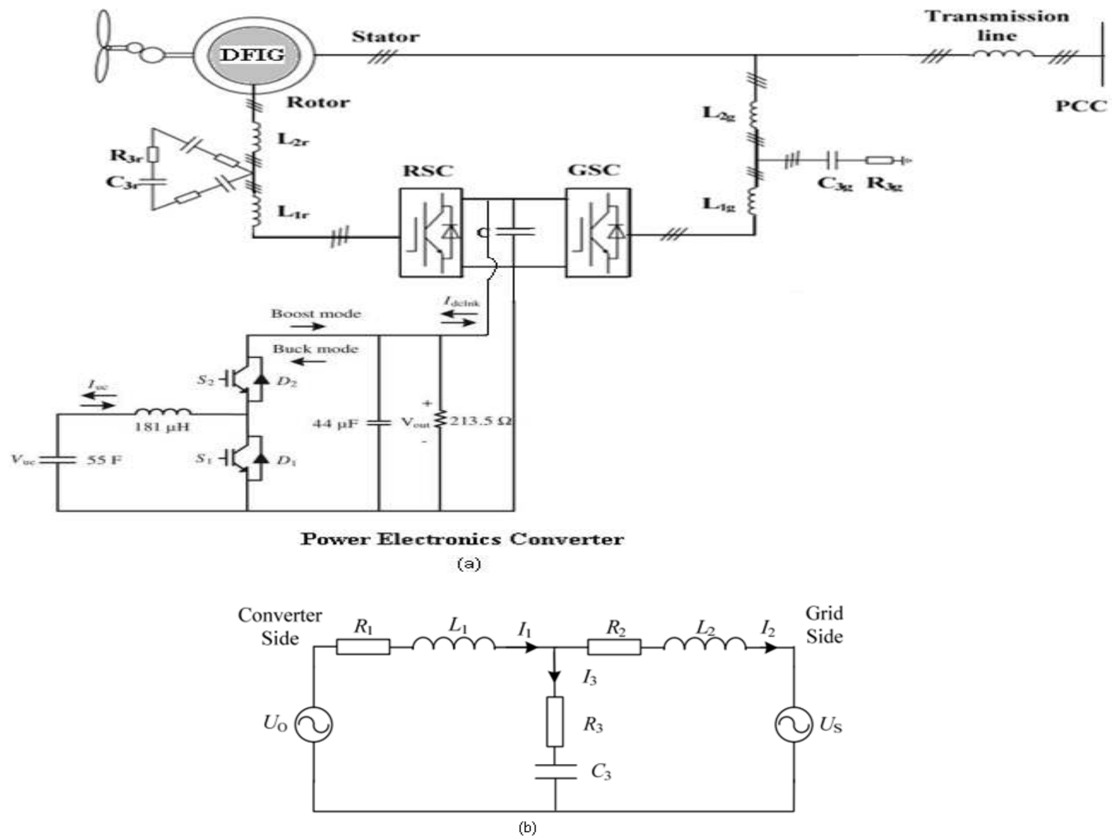

Fig. 1: (a): Configuration of DFIG system; (b): LCL filters equivalent circuit

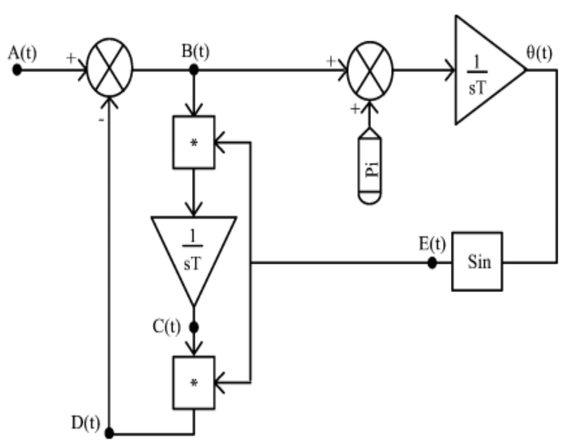

Fig. 2: Reference signal generation methods for RSC and GSC

frame as well as the controller design. Y connected LCL filters and delta connected LCL filters design schemes are applied for GSC and RSC respectively shown in Fig. 4. The 5.6 KW DFIG is presented with 800 V voltage (line to line, 50 Hz). The stator rotor inductance turns and other parameters are listed in the Appendix. The fundamental components of output current for both Converter (GSC and RSC) derived in low frequency. Capacitor branch has been neglected while determine control parameters because it has low pass and high frequency components:

- The equivalent circuit for LCL Shown in Fig. 1 and filters are inserted between DFIG rotor side to RSC as well as GSC to grid. U_0 Is terminal voltage, U_s is grid voltage, L_1, L_2 and are the converter and grid side inductors, respectively. R_1, R_2 are the equivalent resistance of L_1, L_2 respectively. R_3 Is the damping resistor with C_3 capacitor the transfer function between input voltage U_0 and output current I_0 is:

$$\frac{R_3 + C_3 s + 1}{L_1 + L_2 + C_3 s^3 (L_1 + L_2) R_3 C_3 s^2 + (L_1 + L_2) s} \quad (4)$$

Equation (1) is a third order transfer function which is offer high attention in high order harmonics with high frequency operations.

The inductance value should limit the current ripples of I_1 in the range of 15-25% of rated current (Zhan *et al*., 2012). The current I_1 is mainly depends on impedance X_{L1} (impedance of L_1), X_{L2C3} (impedance of L_2 and C_3) and X_{c3} (impedance of C_3). Ripple current is derived by PWM frequency is given by:

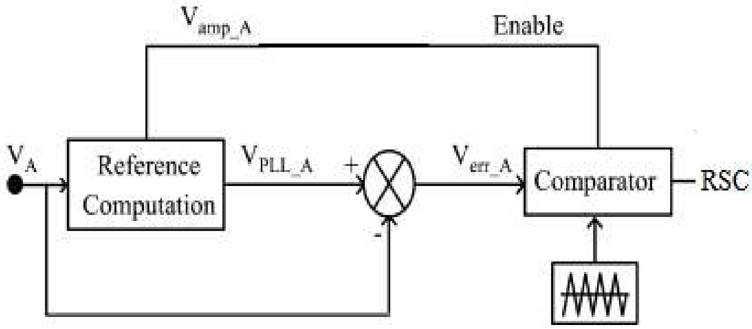

Fig. 3: The control circuit for RSC

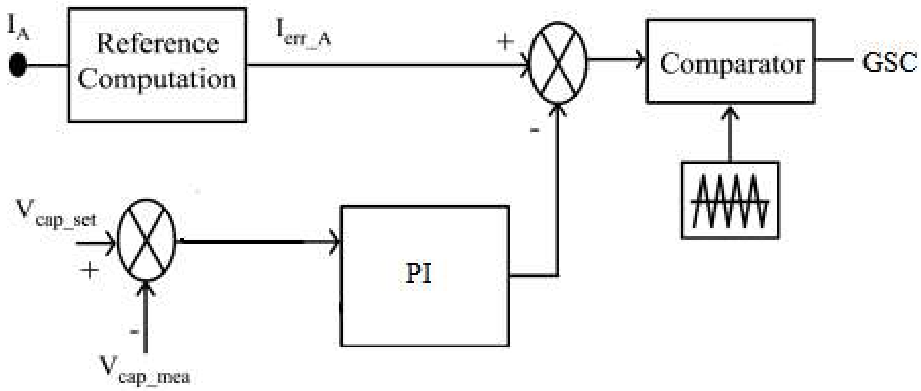

Fig. 4: The control circuit for GSC

$$i_{rip\_max} = \frac{U_{DC}}{8 f_{PWM} L_1} \tag{5}$$

where, U_{DC} dc-link voltage and f_{PWM} is converter switching frequency. Based on desired current ripple i_{rip} obtained by:

$$L_1 \geq \frac{U_{DC}}{8 i_{ripp} f_{PWM}} \tag{6}$$

In order to avoid voltage drop inductor L is limited too and it's given by (Zhan *et al*., 2012):

$$L_1 \leq \frac{\sqrt{U_{DC}^2/3 - U_m^2}}{\omega_B I_m} \tag{7}$$

where, U_m is a peak grid voltage, I_m is a peak grid current and w_B is an angular frequency of grid voltage. High range of capacitor C_3 denotes a low impedance of X_{C3}. C_3 Is designed by following:

$$C_3 \leq 5\% \times \frac{P_{rated}}{3 \times 2\pi f_B U_{rated}^2} \tag{8}$$

where,
P_{rated} = Rated power of converter
f_B = Grid frequency
U_{rated} = RMS value of converter phase voltage

- The current ripple reduction (σ) is minimized through reducing the rate of L_2, C_2 are reduces the current ripple in grid at low level:

$$\sigma = \frac{i_g(f_{PWM})}{i_c(f_{PWM})} = \frac{1}{\left|L_2 C_3 \omega_{PWM}^2 - 1\right|} = 10\% \tag{9}$$

where, $i_g(f_{PWM})$ and $i_c(f_{PWM})$ are the grid current ripple and converter current ripple in the switching frequency limit.

- Resonance frequency w_{res} should be in the range between the ten times of switching frequency and half of the times of switching frequency are given by:

$$10\omega_B < \omega_{res} < 1/2\, \omega_{PWM} \tag{10}$$

Resonance frequency w_{res} for Y connected LCL filters is obtained by:

$$w_{res} = \sqrt{\frac{L_1 + L_2}{L_1 L_2 C_3}} \quad (11)$$

Resonance frequency w_{res} for Δ connected LCL filters is obtained by:

$$w_{res} = \sqrt{\frac{L_1 + L_2}{3 L_1 L_2 C_3}} \quad (12)$$

- The damping resistor is implemented to reduce the complexity and improve the reliability of system. Without damping Resistor (R_3) in Eq. (1) becomes:

$$R_3 = \frac{1}{3 w_{res} c_s} \quad (13)$$

Damping Resistor (R_3) is fixed at one third of impedance C_3 and also in resonance frequency limit.

SIMULATION RESULTS

The presented schemes are implemented and the results are verified in MATLAB/SIMULINK. The proposed new DC-Link control and reference signal generation of back-to back converter are provides a dynamic improvement in power quality in the control of Real and reactive power control and power factor correction. The parameters of proposed DFIG and rotor/stator side LCL filters parameters are used as it given in Table 1 and 2.

The sag is created by applying three phase fault in grid line during 0.2 to 0.3 sec. Sag has been identified and compensated by reference current generation scheme presented in Grid side converter control. DC-Link capacitor voltage constant obtained during 0.3 to 0.5 sec shown in Fig. 5. The combination of the grid side reference current controller and the Rotor side reference voltage controller are easily obtained the performance in active/reactive power control shown in Fig. 6. The predominant LCL filters are applied in design aspects. The Filter design perfectly controls the current flickers in grid side and reduces the harmonics distortion level up to 2.85%.

Table 1: DFIG parameters

Parameters name	Values
Rotor side filters	
Primary inductance L_{1r}	$5e^{-4}$ H
Secondary inductance L_{2r}	$0.05e^{-2}$ H
Rotor side resistance R_{1r}	0.57 Ω
Rotor side inductance L_{1r}	$300e^{-6}$ H
Stator side filters	
Primary inductance L_{1g}	$1e^{-3}$ H
Secondary inductance L_{2g}	$0.73e^{-2}$ H
Stator side resistance (R_{1g})	0.68 Ω
Stator side inductance (L_{1g})	$100e^{-6}$ H

Table 2: LCL filters parameters

Parameters names	Values
Number of Poles (p)	3
Stator Resistance (R_s)	0.023 Ω
Stator inductance (L_s)	0.104 H (pu)
Magnetic inductance (L_m)	2.93 H (pu)
Rotor Resistance (R_r)	0.0396 Ω
Rotor inductance (L_r)	0.106 H
Stator phase voltage (V_a)	690 V
Grid frequency (Hz)	50 Hz
Nominal mechanical rotor speed (rad/sec)	100 (rad/sec)
Rated maximum power (w)	6 KW

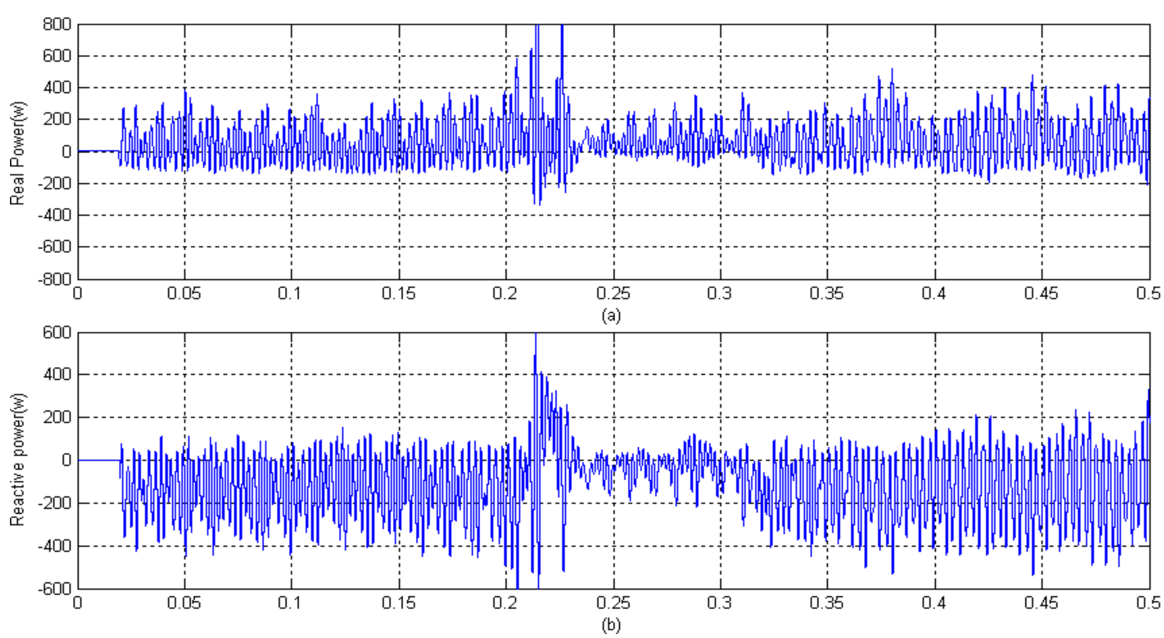

Fig. 5: Dc-link capacitor voltage of proposed scheme

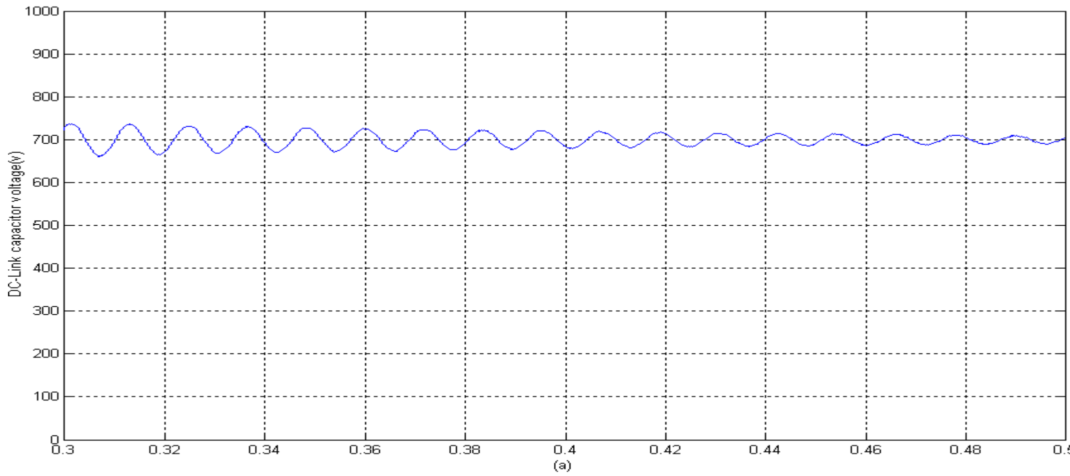

Fig. 6: Active and reactive power for rotor side

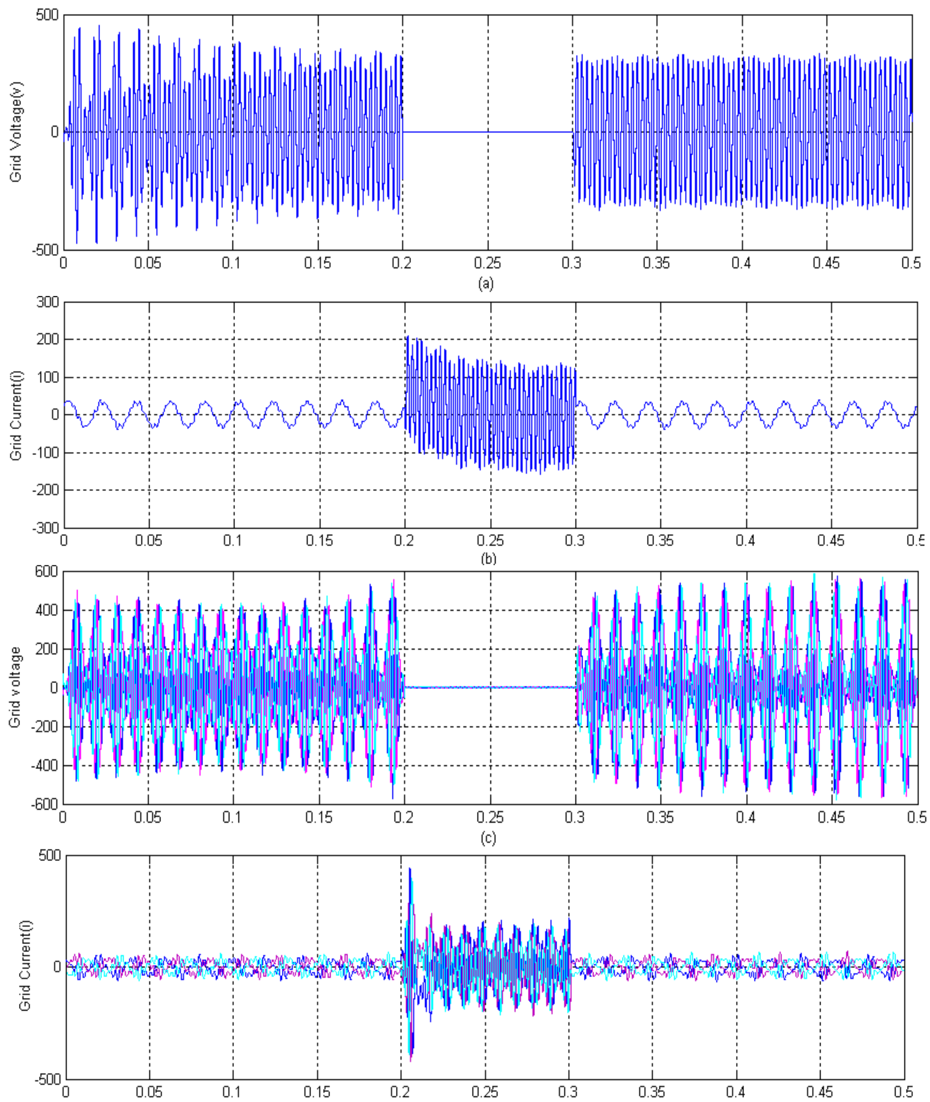

Fig. 7: (a): Per phase grid voltage during sag; (b): Per phase current during sag; (c): Three phase grid voltage during sag; (d): Three phase grid current during sag

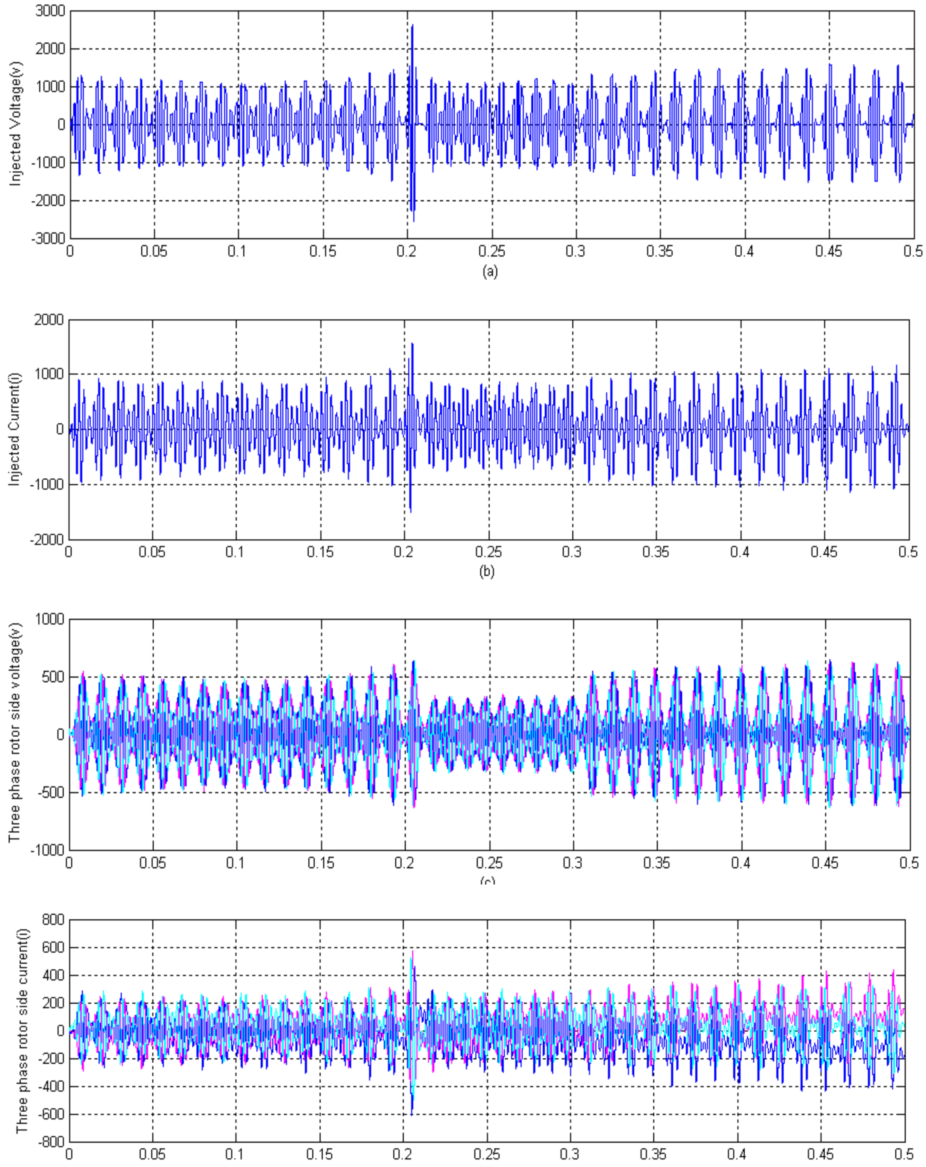

Fig. 8: (a): Per phase injected voltage for rotor side converter; (b): Per phase injected current for rotor side converter; (c): Sag compensated three phase voltage for rotor side; (d): Sag compensated three phase current for rotor side

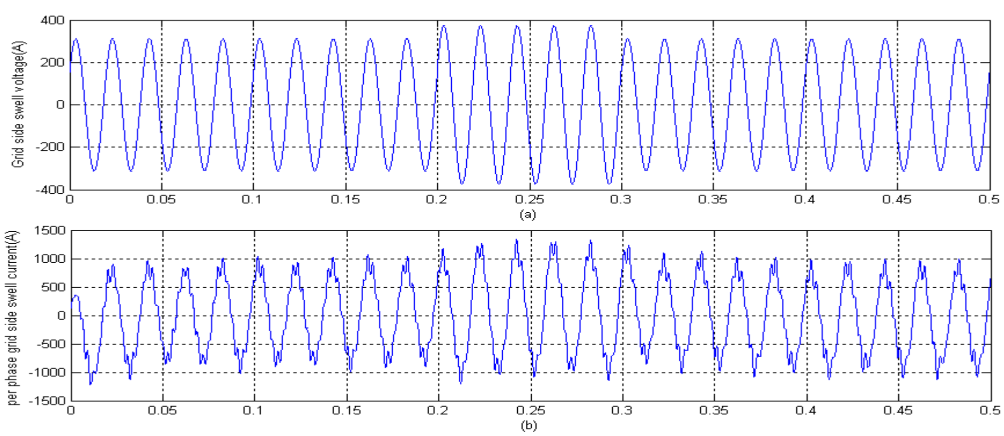

Fig. 9: Per phase grid voltage and current during 20% of swell

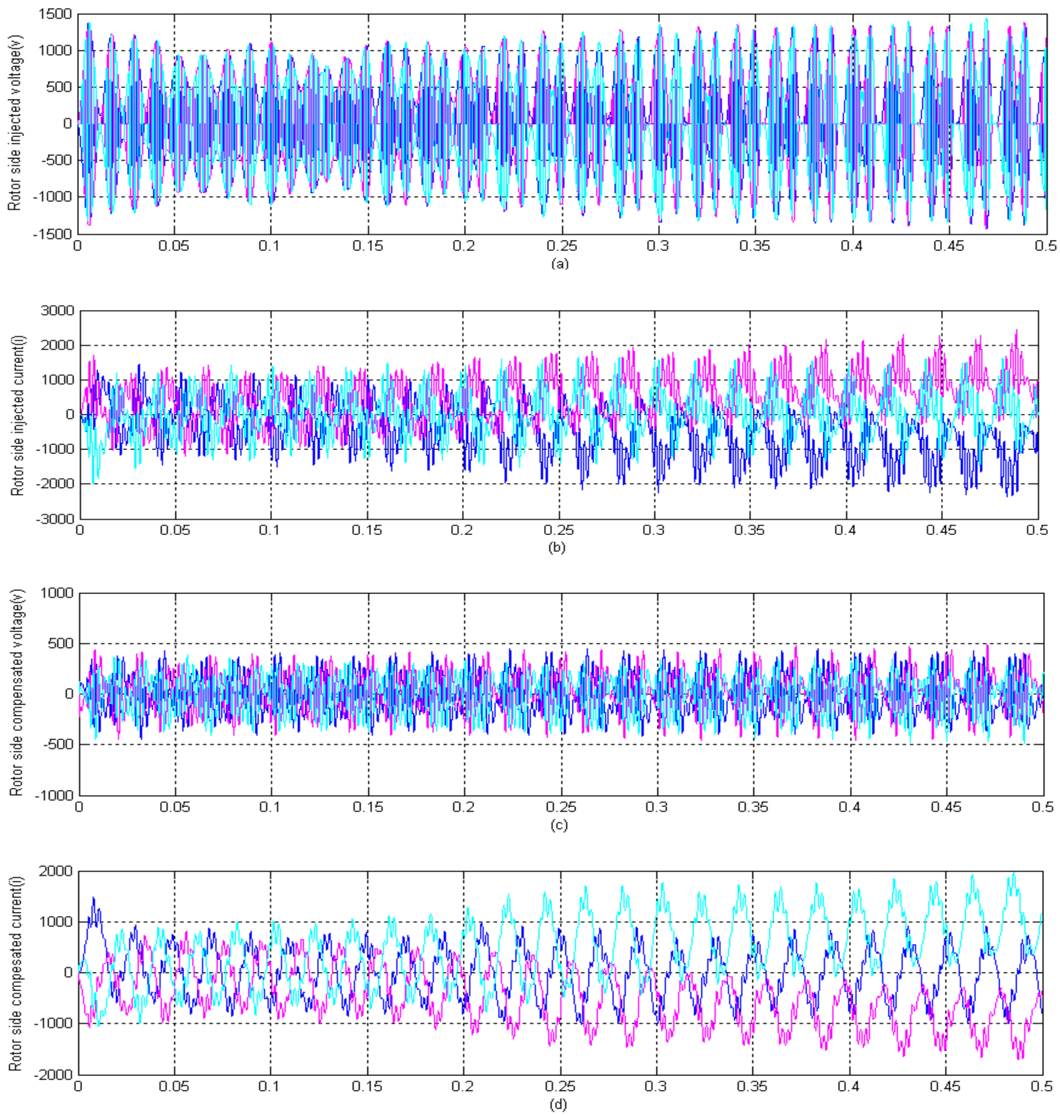

Fig. 10: (a): Per phase injected voltage for rotor side converter during swell; (b): Per phase injected current for rotor side converter during swell; (c): Swell compensated three phase voltage for rotor side; (d): Swell compensated three phase current for rotor side

The voltage and current waveform during sag is shown in Fig. 7. The second order low pass filters are extracted the fault (sag) voltage clearly to find the fault and used to mitigate the fault. The Rotor side sag compensation per phase and three phase voltage and current shown in Fig. 8. The per phase grid side voltage and current waveform during 20% of swell is shown in Fig. 9 and the swell is applied in grid voltage by applying magnitude variation during the time interval 0.2 to 0.3 sec. The Compensation and creation of swell waveform shown in Fig. 10.

CONCLUSION

The active filtering of RSC and GSC provides the effective sag/swell mitigation using new reference signal generation for RSC and GSC. Sag/swell and real/reactive control can be easily obtained through reference signal generation of both voltage and current for both rotor side and Grid side converter. An effective DC-Link Voltage balancing is obtained through Buck-boost chopper for power quality improvement and mitigates the power quality disturbances. LCL filters design and back-to-back converter control helps to each other to improve the power quality. The proposed DC-Link voltage control and back-to-back converter controller are great invention for sag/swell mitigation and power quality improvement.

REFERENCES

Anderson, P.M. and A.A. Fouad, 2002. Power System Control and Stability. 2nd Edn., Wiley, New York, pp: 672.

Branda, M., H. Johal and L. Ion, 2011. Energy storage for LV grid support in Australia. Proceeding of IEEE PES Innovative Smart Grid Technologies Asia (ISGT, 2011), pp: 1-8.

Erickson, R.W. and D. Maksimovic, 2001. Fundamentals of Power Electronics. 2nd Edn., Kluwer, Norwell, MA, USA.

European Standard EN 50160, 2002. Voltage characteristics of electricity supplied by public distribution systems. Low Voltage Directive (LVD), Standardisation Policy.

Figueroa, D.J., R.R. Avila and M.B.C. Salles, 2013. Analysis of transmission systems with high penetration of wind power using DFIG based wind farms during voltage sags. Proceeding of International Conference on Clean Electrical Power (ICCEP), pp: 361-367.

Global Wind Energy Council/GWEC, 2013. Global Wind Report: Annual Market Update 2012. GWEC Secretariat, Brussels.

Granados-Lieberman, D., R.J. Romero-Troncoso, R.A. Osornio-Rios A. Garcia-Perez and E. Cabal-Yepez, 2011. Techniques and methodologies for power quality analysis and disturbances classification in power systems: A review. IET Gener. Transm. Dis., 5(4): 519-529.

Hingorani, N.G., 1995. Introducing Custom Power. IEEE Spectrum, 32(6): 4l-48.

Karimi-Ghartemani, M., M.R. Iravani and F. Katiraei, 2005. Extraction of signals for harmonics, reactive current and network-unbalance compensation. IEE P-Gener. Transm. D., 152(1): 137-143.

Khadkikar, V. and A. Chandra, 2011. UPQC-S: A novel concept of simultaneous voltage sag/swell and load reactive power compensations utilizing series inverter of UPQC. IEEE T. Power Electr., 26(9): 2414-2425.

Liserre, M., F. Blaabjerg and S. Hansen, 2005. Design and control of an LCL-filter-based three-phase active rectifier. IEEE T. Ind. Appl., 41: 1281-1291.

Teke, A., L. Saribulut and M. Tumay, 2011. A novel reference signal generation method for power-quality improvement of unified power-quality conditioner. IEEE Trans. Power Deliver., 26(4): 2205-2214.

Zadehbagheri, M., R. Ildarabadi and M.B. Nejad, 2013. Sliding mode control of a Doubly-Fed Induction Generator (DFIG) for wind energy conversion system. Int. J. Sci. Eng. Res., 4(11).

Zhan, P., W. Lin, J. Wen, M. Yao and N. Li, 2012. Design of LCL filters for the back-to-back converter in a doubly fed induction generator. Proceeding of IEEE Innovative Smart Grid Technologies-Asia (ISGT Asia), pp: 1-6.