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Ride-Through Analysis of Doubly Fed Induction Wind-Power Generator with SGSC under Unbalanced Grid Voltage Conditions

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Abstract:
This paper presents a ride-through analysis of control way for a doubly fed induction generator DFIG based wind-power generation system with series grid-side converter (SGSC) underneath unbalanced conditions of network voltages. The analyses of the DFIG with SGSC running under network unbalance are delineated. That by injecting a series management voltage generated from the SGSC to balance the generator stator voltage. This unpleasant effects of voltage unbalance upon the DFIG, like stator and rotor current unbalances, electromagnetic torque and power pulsations may be removed, then the standard vector management scheme for the rotor-side converter remains fully force underneath unbalanced conditions. As the same time, 3 control targets for the parallel grid-side converter (PGSC) are taken, together with eliminating the oscillations within the total real power or reactive power, or eliminating no order negative-sequence current injected to the network. In addition a definite current reference generation scheme for the PGSC has been made in the way to get more develops the operation carried out in the total work system. At last the proposed coordinated approach to the control scheme for the DFIG system with SGSC has been made certain by the simulation results of a MW DFIG based wind turbine with SGSC and testing results on a laboratory scale experimental to arrange underneath little steady-state grid voltage unbalance.

Keywords*: Series grid-side converter (SGSC), doubly fed induction generator (DFIG), voltage unbalances of grid network, wind-power generation*

1. Introduction

With the increased penetration of wind energy into power systems everywhere the globe, wind turbines supported doubly fed induction generators (DFIGs) are wide used for large-scale wind-power generation. Nowadays, a lot of and a lot of DFIG-based wind turbines are put in in remote areas or offshore wherever rural grids are principally weak and voltage unbalance caused by asymmetrical hundreds or grid faults typically happens not like alternative generators with the full-sized grid- connected converters, the DFIG is incredibly sensitive to unbalanced grid voltage as its stator coil is directly connected to the grid. The stator coil and ro- tor currents can be extremely unbalanced even underneath a awfully tiny unbalanced grid voltage condition. The unbalanced cur- rents can result in considerably double-supply frequency oscillations in generator's power output and magnetism torque, deteriorating the output power quality and reducing the period of time of the mechanical parts. What is more, the unbalanced currents will produce unequal heating within the stator coil and rotor windings, which can degrade the insulation of the windings. As a result, DFIGs while not unbalanced voltage management could have to be compelled to be disconnected from the grid once network voltage unbalance is quite 6 % that couldn't be accepted in today's wind-energy application. So as to fulfill the wants of the new grid codes, DFIGs ought to be ready to operate underneath a little steady-state voltage unbalance while not disconnection.

Recently, some increased operation and management schemes are investigated for DFIG systems underneath unbalanced grid voltage conditions. In the stator coil voltage balance is enforced by injecting compensation currents into the grid victimization parallel grid-side device (PGSC), therefore the pulsations within the generator's power output and currents unbalance will be reduced. However, as negative-sequence currents delivered from the PGSC to sup- ply the grid, the whole active and reactive power outputs of the DFIG system still oscillate at double the grid frequency; additionally, each this rating of the PGSC and also the negative-sequence impedance of the grid extremely impacts on the effectiveness of such compensation theme. From the purpose of read of enhancing the complete DFIG system performance throughout network voltage unbalance, some coordinated management schemes for each the PGSC and also the rotor-side device (RSC) are discussed to enhance the general operational performance. As mentioned in the twin current proportional integral (PI) controllers within the positive and negative synchronous organizations or the proportional resonant current controllers within the stator coil stationary reference frame are adopted to produce the different operation functionalities, i.e., eliminating the oscillations within the total active or reactive power output from the complete system, or eliminating negative-sequence currents injected to the grid. However, considering the restricted RSC and PGSC management variables, the planned ways cannot eliminate the stator coil and rotor current unbalances in DFIG and also the current unbalance in PGSC at the same time underneath unbalanced voltage conditions. Consequently, unequal heating within the stator coil and rotor windings or within the line reactors still exist, which can degrade the period of time of the windings or coupled inductors insulation materials, as remote wind farms connected to weak networks oft are subject to undergoing voltage unbalance level on the far side a pair of.

The main reason inflicting stator coil and rotor current unbalances, magnetism torque, and power pulsations within the DFIG is stator coil voltage unbalance: if the negative-sequence voltage at the generator's stator coil terminal will be eliminated and solely balanced positive-sequence voltage is left throughout network unbalance, the adverse effects of unbalance upon the DFIG are removed naturally. a lot of recently, a replacement DFIG configuration with associate degree additional grid-side device asynchronous with the generator's stator coil windings has been planned by Flannery and Venkataramanan so as to tackle the low voltage ride-through (LVRT) operation. Because the stator coil terminal voltage will be flexibly controlled by control the output voltage of series grid-side device (SGSC), the DFIG will effectively deal with varied deep voltage sag conditions by suppressing or eliminating the transient dc and negative-sequence flux parts, and also the glorious LVRT operation performance has been valid by victimization simulation and experiment tests throughout symmetrical or unsymmetrical grid faults. Not like alternative LVRT methodology employing a series dynamic voltage renovator (DVR) mentioned in, the DFIG system with SGSC can even deal with the case of long-run steady-state grid voltage unbalance. Considering that tiny grid voltage unbalances occur a lot of oft than severe voltage dips, associate degree improved management theme is utilized to additional extend the applications of the new DFIG system with SGSC. By coordinately dominant the SGSC, PGSC, and RSC, 3 selective management targets for PGSC are obtained to boost the unbalanced operation capability. Meanwhile the VA ratings and power losses of the SGSC and therefore the the series transformer have also been calculated. However, the planned positive- and negative-sequence dq-axis reference parts of the PGSC's currents are deduced by presumptuous that PGSC's reactive power being zero throughout net- work unbalance and solely simulation results is given. Taking into consideration the actual fact that PGSC has versatile management capability, some reactive power generated from the PGSC will be delivered into the grid, which suggests that the PGSC will participate within the auxiliary reactive power regulation throughout the network un- balance. Consequently, it's necessary for the PGSC to produce the desired reactive power support to the grid; therefore, correct current reference generation ought to be achieved for the PGSC increased management.

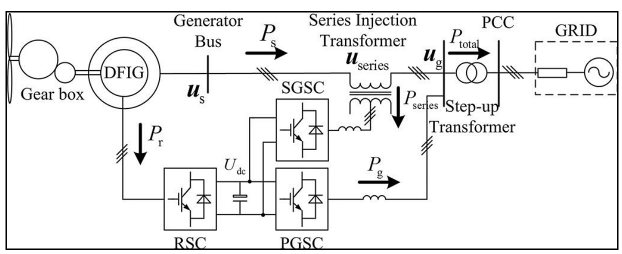

Figure 1: Configuration of DFIG with SGSC

In the figure DFIG is connected to wind turbine, where the generator stator is connected to grid through a series transformer and step-up transformer.

Here a feed back loop is connected that containing of SGSC, PGSC and RSC. When system is unbalance condition this converter loop will generate the series voltage with control operation as explained in further, this injected through series transformer in order to balance the condition, as this way power oscillations and negative sequence currents also taken into account for coordination operation of converters explained that to be removed.

2. Operation Behaviour of DFIG System with SGSC During Network Voltage Unbalance

During network voltage unbalance sags in order to make of less effect (By Acting Against) the effect of the not order network electric force a series balancing action electric force guide produced by the SGSC is putt balance the stator electric force needing payment to the existence of the series transformer impedance there is still a small, little point or amount unlike between the positive order network electric force and DFIG stator electric force as an outcome of that a positive order voltage should be put to make payment etc. For loss the impedance electric force drops.

Fig. 2 represents the schematic diagram of the proposed control strategy for the DFIG system with SGSC underneath unbalanced grid network voltage conditions. Because of the unbalance, a phase locked loop is implemented to calculate the frequency and phase angle of the positive-sequence grid voltage. In the positive and negative-sequence reference frames, the final regulating voltages for both the SGSC and PGSC are obtained, and these voltages are used as reference voltages with required space vector pulse width modulation techniques.

2.1. SGSC

In order to reduce the effect of the negative-sequence grid voltage, a series compensation voltage vector generated by the SGSC is injected to balance the stator voltage. Due to the existence of the series transformer impedance, there is still a slight difference between the positive-sequence grid voltage and DFIG stator voltage. Consequently, a positive-sequence voltage vector should be injected to compensate

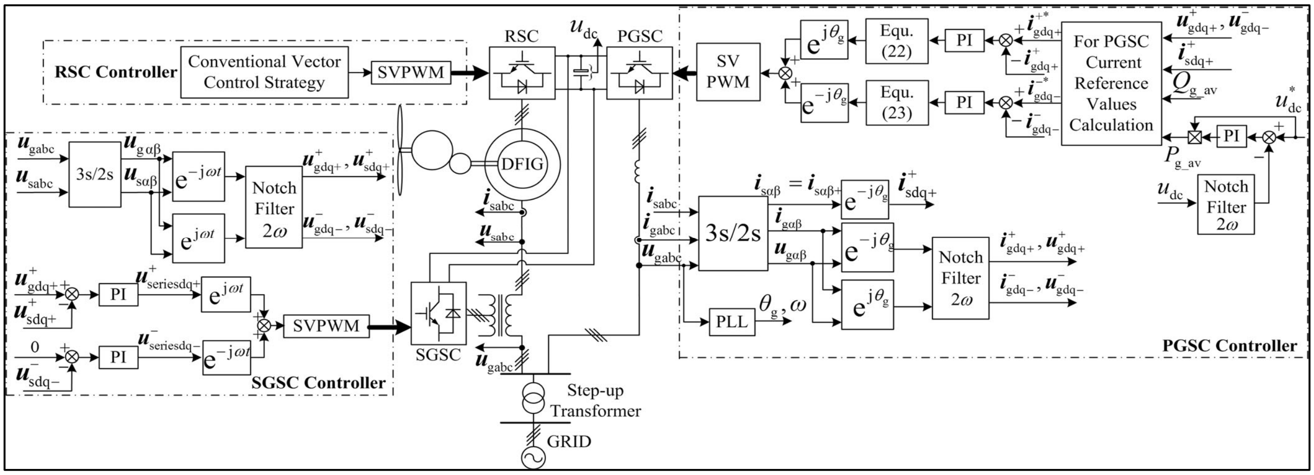

Figure 2: Schematic diagram of the proposed control scheme
For the DFIG system with SGSC

the impedance voltage drop, making the stator voltage keep in line with the positive sequence grid voltage. As the stator currents of the DFIG are symmetrical by balancing the generator stator terminal voltage, the currents flowing into SGSC through the series transformer are also balanced, which are equal to the positive-sequence stator currents of DFIG. Underneath unbalanced network conditions, the instant active and reactive power flowing through the SGSC contain average dc elements and double-supply frequency oscillations, which might be pictured as as

$$P_{series} = P_{series\_av} + P_{series\_cos2} \cos 2\omega t + P_{series\_sin2} \sin 2\omega t$$

$$Q_{series} = Q_{series\_av} + Q_{series\_cos2} \cos 2\omega t + Q_{series\_sin2} \sin 2\omega t \quad (1)$$

2.2. PGSC

Assume that PGSC is directly connected to the grid, PGSC operation behavior is similar to a grid connected voltage source converter system. The real and reactive power from the PGSC to the grid can be defined as

$$P_g = P_{g\_av} + P_{g\_sin2} \sin 2\omega t + P_{g\_cos2} \cos 2\omega t$$
$$Q_g = Q_{g\_av} + Q_{g\_sin2} \sin 2\omega t + Q_{g\_cos2} \cos 2\omega t \quad (2)$$

2.3. RSC

As eliminating the negative-sequence stator voltage, the stator terminal voltages of DFIG are balanced during network unbalance. Thus, the conventional vector control strategy for the RSC remains in full force under unbalanced grid voltage conditions. With effective control of SGSC, the unpleasant effects of voltage unbalance upon DFIG such as large stator and rotor current unbalances, electromagnetic torque and power pulsations will be eliminated simultaneously,

$$i_{s-} = 0,\ i_{r-} = 0,\ T_{esin2} = T_{ecos2} = 0$$
$$P_{ssin2} = P_{scos2} = 0,\ Q_{ssin2} = Q_{scos2} = 0$$
$$P_{rsin2} = P_{rcos2} = 0,\ Q_{rsin2} = Q_{rcos2} = 0. \quad (3)$$

3. VC System for The SGSC and PGSC

As that the PGSC is directly connected to the network its operation behavior is similar to network connected voltage source converter system. Here network grid voltages and induction generator-stator voltages may be referred as 2 synchronous dq reference frames rotating at $+\omega$ and $-\omega$, in sequentially. As double-supply frequency oscillations in network voltage components are generated when positive or negative – sequence voltages are changed to dq-axes rotating in the reverse direction. As a result , notch filters tuned at double-ω are used to decrease the pulsation parts oscillating at increased power supply frequency, and dc parts can be obtained by decayed the stator and grid voltages. So as to get doubly-fed induction generator stator voltage is equal to the positive sequence voltage of grid network voltage. The negative and positive-sequence serially connected grid side converter controlled voltages represented in Fig. 2. The control of parallel grid side converter same as to control of series connected grid side converter, in steady state notch filters which removes the double-supply frequency pulsation parts are used to gain the dc components of grid network side voltages and currents on the negative- or positive-sequence synchronous reference frames rotating at $\pm\omega$. It must be pointed out that the projected control scheme desires some notch filters to filter out the double-frequency supply terms in the rotating reference frames, which strength introduce some time delays of the feedback signal. Certainly if the resonant controllers are used, the electric force in the series grid side converter and currents in the parallel grid side converter may be straightly regulated in the stationary frame exclusive of sequential component decompositions.

4. Coordinated Control of SGSC, PGSC and RSC

As early seen in section 2.1, the important task of the SGSC running under network unbalance is to maintain the DFIG stator voltage is along the lines of positive–sequence grid voltage, as SGSC has the control target as,

$$u_{s+} = u_{g+}$$

$$u_{s-} = 0. \tag{4}$$

As positive-sequence part of DFIG stator terminal voltage vector could be managed to equal to that of grid voltage vector, while negative-sequence part of DFIG stator voltage vector could be managed to zero.

For PGSC under unbalanced grid voltage conditions, four grid currents $i^{+}_{g\,d+}$, $i^{+}_{g\,q+}$, i^{-}_{gd-}, and $i^{-}_{g\,q-}$ may be controlled to boost the system performance. As P_{g_av} and Q_{g_av} average real and reactive power of grid side apart of this PGSC to be also to control 2 power oscillating terms. PGSC controlled to reach the three control targets mentioned as,

Target 1: to decrease the oscillations of the total DFIG system's total active power getting into the grid;

Target 2: to eliminate the oscillations of the total DFIG system's total reactive power getting into the grid;

Target 3: to restrain the total system's negative-sequence currents injected to the grid.

For target 1 the total active or real power of the DFIG system with SGSC can be mentioned as

$$\begin{aligned} P_{total} = P_S - P_{series} + P_g = (P_{s\_av} - P_{series\_av} + P_{g\_av}) \\ + (0 - P_{series\_sin2} + P_{g\_sin2}) \sin 2\omega t \\ + (0 - P_{series\_cos2} + P_{g\_cos2}) \cos 2\omega t. \end{aligned} \tag{5}$$

So as to remove the oscillations in the real power, the oscillating terms ought to be adequate zero with the management of PGSC, as,

$$-P_{series\_sin2} + P_{g\_sin2} = 0,\ -P_{series\_cos2} + P_{g\_cos2} = 0. \tag{6}$$

For Target 2 the total reactive power of the DFIG system with SGSC can expressed as

$$\begin{aligned} Q_{total} = Q_s - Q_{series} + Q_g = (Q_{s\_av} - Q_{series\_av} + Q_{g\_av}) \\ + (0 - Q_{series\_sin2} + Q_{g\_sin2}) \sin 2\omega t \\ + (0 - Q_{series\_cos2} + Q_{g\_cos2}) \cos 2\omega t. \end{aligned} \tag{7}$$

For remove the oscillation of the entire reactive power, the oscillating parts ought to be equal zero by managing of PGSC, as

$$-Q_{series\_sin2} + Q_{g\_sin2} = 0,\ \ -Q_{series\_cos2} + Q_{g\_cos2} = 0. \tag{8}$$

As in Target 3 the overall current send to grid is sum of currents from DFIG stator side and grid network side as revealed in Fig. 1. The negative-sequence current of the DFIG stator side is removed the result is intended with manage of SGSC, as make the goal of of no negative-sequence current injected to the grid network designate that currents generated from PGSC are balanced, this negative-sequence current reference mentioned as

$$i^{-*}_{gd-} = 0,\ \ i^{-*}_{gq-} = 0. \tag{9}$$

While RSC the DFIG stator terminal voltage is still balanced. As running under grid unbalance vector control scheme can remain in full force.

5. Simulation Study

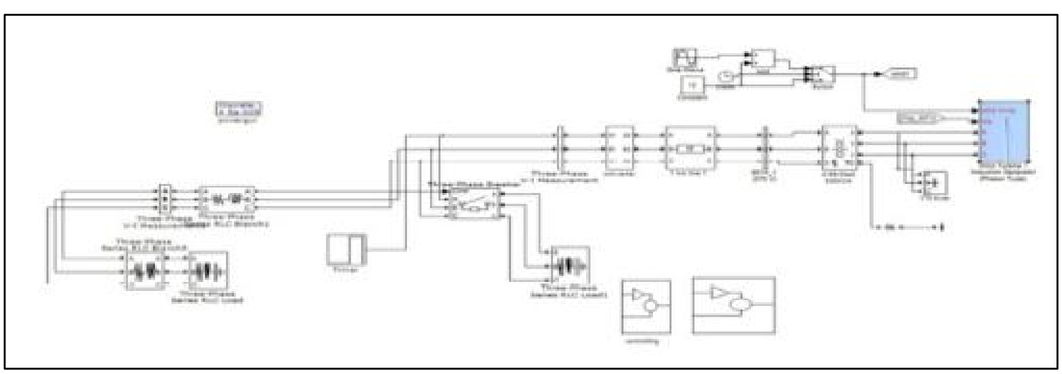

Figure 3: Simulation diagram

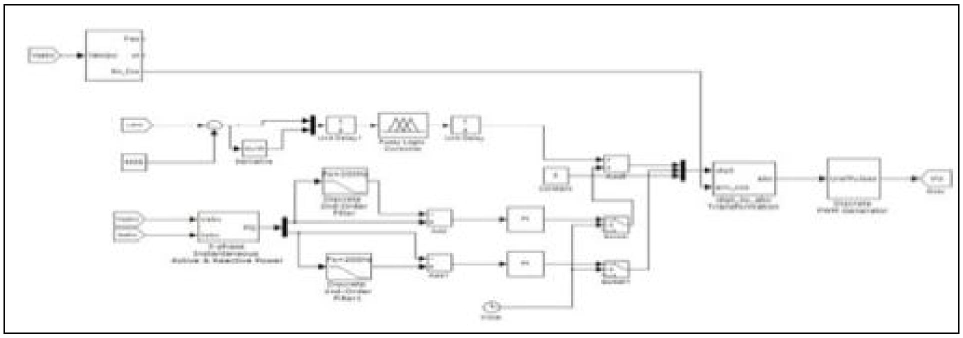

Figure 4: Control technique block

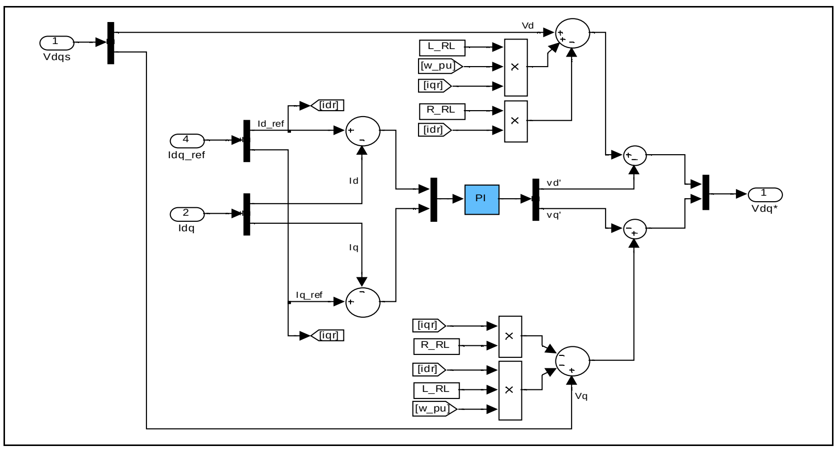

Figure 5: Grid side control Current regulator & Rotor side control

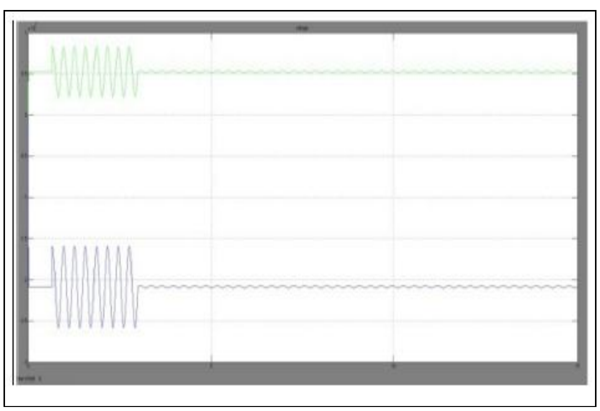

Figure 6: voltage and control voltage

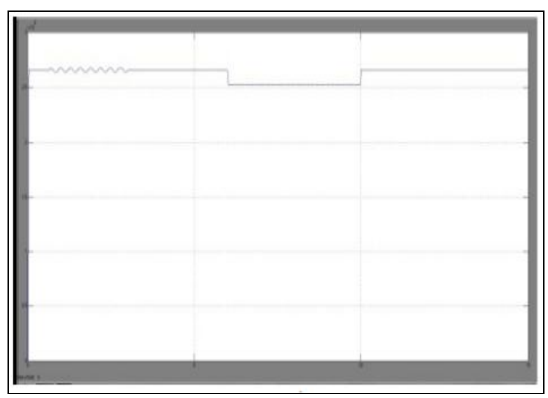

Figure 7: Speed of Generator

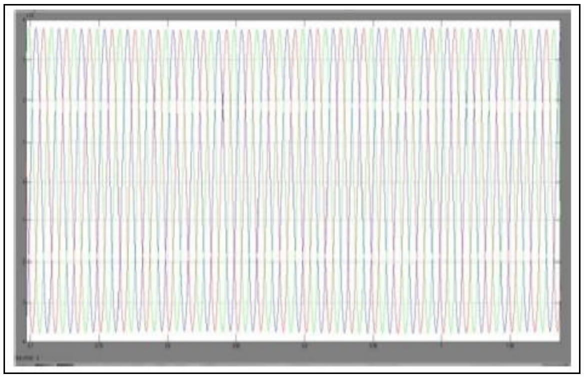

Figure 8: V_{abc} controlled voltage

Figure 9: P (Active power) Q(Reactive power)

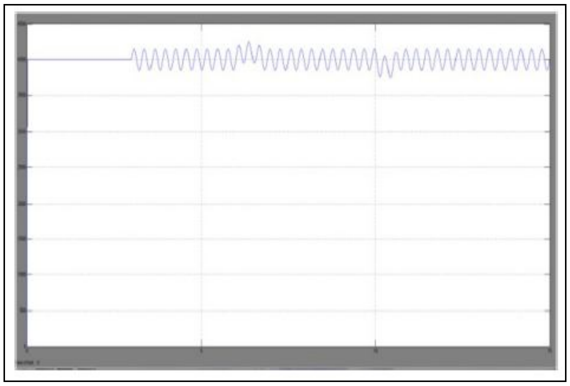

Figure 10: DC Voltage

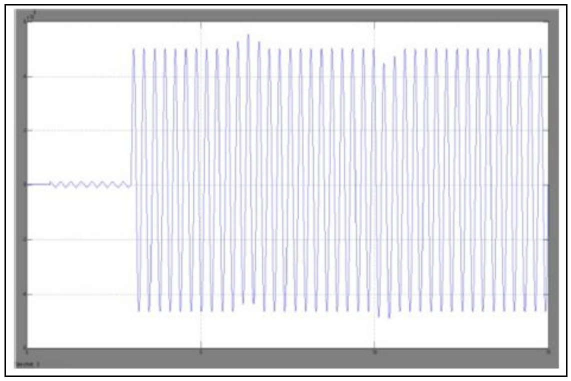

Figure 11: Grid voltage

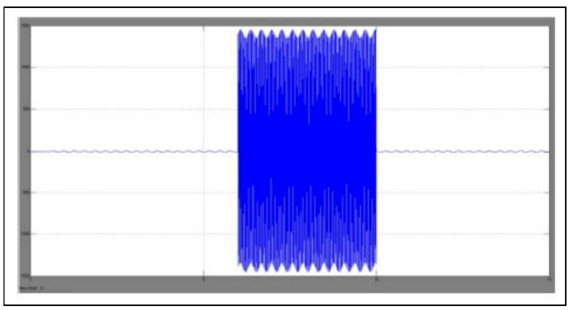

Figure 12: SGSC Injected voltage

6. Conclusion

Ride-through analysis of doubly fed induction wind power generator with SGSC under unbalanced grid voltage conditions has been investigated in this paper. The accurate current reference generation scheme for PGSC has been proposed, and a coordinated control scheme for SGSC, PGSC and RSC is discussed. Control targets for PGSC to remove the oscillations in real or reactive power , or getting total balanced current from the whole system have been obtained respectively, While the RSC is controlled with the conventional VC strategy to achieve the goals of zero oscillations in DFIG's active and reactive power and balanced stator and rotor currents in the three-phase windings under unbalanced voltage conditions. Furthermore, the function of SGSC not necessary to be changed running both normal grid condition and the unbalanced grid voltage condition for 3 control schemes.

And dynamic dual pi controllers for the SGSC and PGSC proposed. The proposed coordinated control schemes have been validated using both simulation and laboratory experimental tests, and the results show that control operation for doubly fed induction wind power generator with SGSC under unbalanced grid voltage conditions can be significantly improved entire system by removing oscillations in the power, negative-sequence currents and balancing the total current generated in the system.

7. References

1. E. Muljadi, T. Batan, D. Yildirim, and C. P. Butterfield, "Understanding the unbalanced-voltage problem in wind turbine generation," in Proc. IEEE Ind. Appl. Conf., 1999, vol. 2, pp. 1359–1365.
2. T. Brekken and N. Mohan, "A novel doubly-fed induction wind generator control scheme for reactive power control and torque pulsation compensation under unbalanced grid voltage conditions," in Proc. IEEE Power Expo. Spec. Conf., Jun. 2003, vol. 2, pp. 760–766.
3. R. Piwko, N.Miller, J. Sanchez-Gasca, X. Yuan, R. Dai, and J. Lyons, "Integrating large wind farms into weak power grids with long transmission lines," in Proc. IEEE Int. Power Electron. Motion Control Conf., 2006, vol. 3, pp. 1122–1128.
4. J. Kearney, M. F. Conlon, and E. Coyle, "The integrated control of the rotor side and grid side converters in a DFIG to reduce both power and torque pulsations during network voltage unbalance conditions," in Proc. IEEE Int. Univ. Power Energy Conf., Sep. 2009, pp. 1–5.
5. L. Xu and Y.Wang, "Dynamic modeling and control of DFIG based wind turbines under unbalanced network conditions," IEEE Trans. Power Syst, vol. 22, no. 1, pp. 314–323, Feb. 2007.
6. S. Seman, J. Niiranen, and A. Arkkio, "Ride-through analysis of doubly fed induction wind-power generator under unsymmetrical network disturbance," IEEE Trans. Power Syst., vol. 21, no. 4, pp. 1782–1789, Nov. 2006.
7. W. Qiao and R. G. Harley, "Improved control of DFIG wind turbines for operation with unbalanced network voltages," in Proc. IEEE Ind. Appl. Soc. Annu. Meet., Oct. 2008, pp. 1–7.
8. T. Brekken and N. Mohan, "Control of a doubly fed induction wind generator under unbalanced grid voltage conditions," IEEE Trans. Energy Conv., vol. 22, no. 1, pp. 129–135, Mar. 2007.
9. R. Pena, R. Cardenas, E. Escobar, J. Clare, and P. Wheeler, "Control strategy for a doubly-fed induction generator feeding an unbalanced grid or stand-alone load," Electr. Power Syst. Res., vol. 79, no. 2, pp. 355–364, 2009
10. Y. Zhou, P. Bauer, J. A. Ferreira, and J. Pierik, "Operation of grid connected DFIG under unbalanced grid voltage condition," IEEE Trans. Energy Conv, vol. 24, no. 1, pp. 240–246, Mar. 2009.