Controlling Zero Sequence Component in DVR for Compensating Unbalanced Voltage Dip of a DFIG

JiHan Ko*, Quach Ngoc Thinh**, SeongHuyn Kim***, Eel-Hwan Kim****

* Multidisciplinary Graduate School for Wind Energy, Jeju National University, S. Korea
, * Department of Electrical Engineering, Jeju National University, Jeju, S. Korea
**** Department of Electrical Engineering, Jeju National University, Jeju, S. Korea, ehkim@jejunu.ac.kr

Abstract

The dynamic voltage restorer (DVR) is an effective protection device for wind turbine generator based on doubly-fed induction generator (DFIG) operated under the unbalanced voltage dip conditions. The compensating voltages of DVR depend on the voltage dips and on the influence of the zero sequence components. If the Y_0/Δ step-up transformers are used, there are no zero sequence components on the DFIG side. However, if the Y_0/Y_0 step-up transformers are used, the zero sequence components will appear during faults. The zero sequence components result in the high insulation costs and the asymmetric of the terminal voltages. This paper proposes a method for controlling zero sequence components in DVR to protect DFIG under unbalanced voltage dips. Simulation results are presented to verify the effectiveness of the proposed control method.

Key words: Dynamic voltage restorer (DVR), Doubly-fed induction generator (DFIG), Unbalanced voltage dip, Zero sequence component.

1. Introduction

Nowadays, the wind farm has contributed a large amount of power in grid power system. Therefore, a disconnection of wind farm from faulty events will cause a power quality problem on grid system. The new grid codes required wind turbine based on DFIG must stay connected when an unbalanced voltage dip occurs. The DVR is an effective protection device for sensitive loads, as DFIGs, operated under the unbalanced voltage dip conditions [1]-[2]. Almost all researches only analyze the restoration of positive sequence and compensation of negative sequence components, while the effects of zero sequence components in compensating voltages of DVR are ignored. In DFIG systems connected to grid, if the Y_0/Δ step-up transformers are used, there are no zero sequence components on the DFIG side. However, nowadays the Y_0/Y_0 step-up transformers are used increasing in distribution systems. Thus, the zero sequence components will appear on the DFIG side during faults. In [3], the author presents a method for mitigating zero sequence effects in DVRs by providing a circulation path within the DVR for zero sequence current. This paper proposes a method for controlling zero sequence components in DVR to protect DFIG under unbalanced voltage dips. In this control method, three phases of compensating voltages are controlled as three single phase separately in stationary reference frame. With proposed control method, the DVR will compensate fully the unbalanced voltage dips, while the DFIG can operate normally during faults.

2. Main subject

2.1 The operation of DFIG

The DFIG system used in this paper is shown in Fig. 1.

The aims of the rotor side converter (RSC) control are to control the stator active and reactive power independently. The active and reactive power can be expressed by

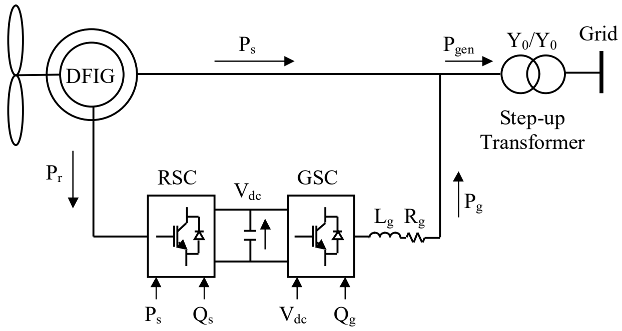

Fig. 1 Schematic diagram of a doubly-fed induction generator based on wind generation system

$$P_s = -\frac{3}{2}\frac{L_m}{L_s}V_{sq}I_{rq}\text{, and } Q_s = \frac{3}{2}\frac{V_{sq}}{L_s}\left(\psi_{sd} - L_m I_{rd}\right) \quad (1)$$

The aims of the grid side converter (GSC) control are to maintain the dc-link capacitor voltage constant and to ensure a converter operation with unity power factor. The dc-link voltage can be expressed by

$$C\frac{dV_{dc}}{dt} = I_r - I_g \quad (2)$$

2.2 The proposed control method

The proposed diagram for connecting the DVR to protect for DFIG system is shown in Fig. 2. As mentioned before, the use of star-star step-up transformer in distribution system will introduce a zero sequence component in supply voltages during unbalanced voltage dip faults. This zero sequence component will propagate

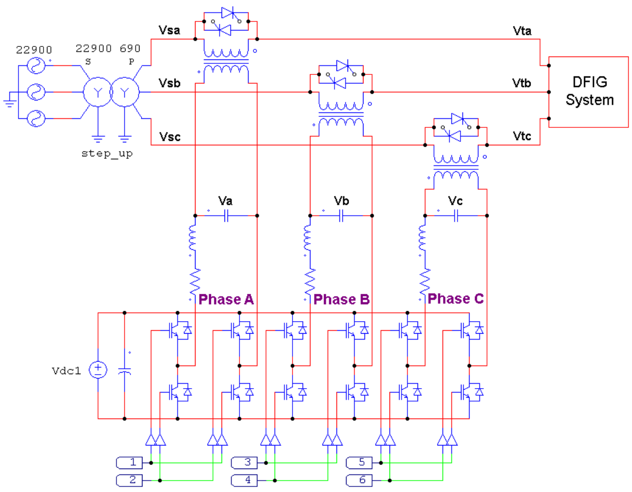

Fig. 2 Schematic diagram of DFIG system with DVR. V_{sa}, V_{sb}, and V_{sc} are three-phase supply voltages. V_a, V_b, and V_c are three-phase compensating voltages. V_{ta}, V_{tb}, and V_{tc} are three-phase terminal voltages of DFIG system.

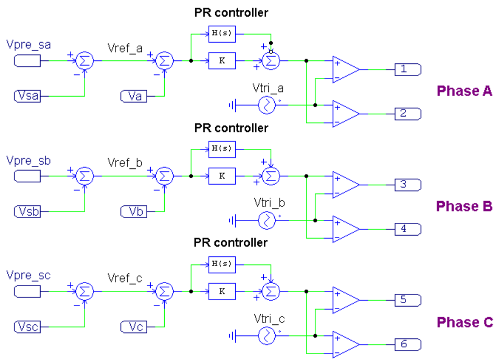

Fig. 3 The proposed control method of DVR for controlling zero sequence component. V_{pre_sa}, V_{pre_sb}, and V_{pre_sc} are three-phase prefault voltages. V_{ref_a}, V_{ref_b}, and V_{ref_c} are three-phase reference compensating voltages. The transfer function of PR: $G_{PR} = K_p + K_I.\omega_c.s/(s^2+2.\omega_c.s+\omega_e^2)$.

into terminal voltages if it is not eliminated fully in DVR. By applying Kirchhoff's voltage law, the zero sequence component of terminal voltages can be expressed by

$$V_{to} = V_{so} + V_o \tag{3}$$

where V_{so}, V_o, and V_{to} are zero sequence components of supply voltage, compensating voltage, and terminal voltage, respectively.

In order to suppress zero sequence component in terminal voltages, the DVR must generate a zero sequence component which will be equal in magnitude and opposite in direction to the zero sequence component present in the supply voltages. This means that

$$V_o = -V_{so} \tag{4}$$

The zero sequence component of compensating voltages is

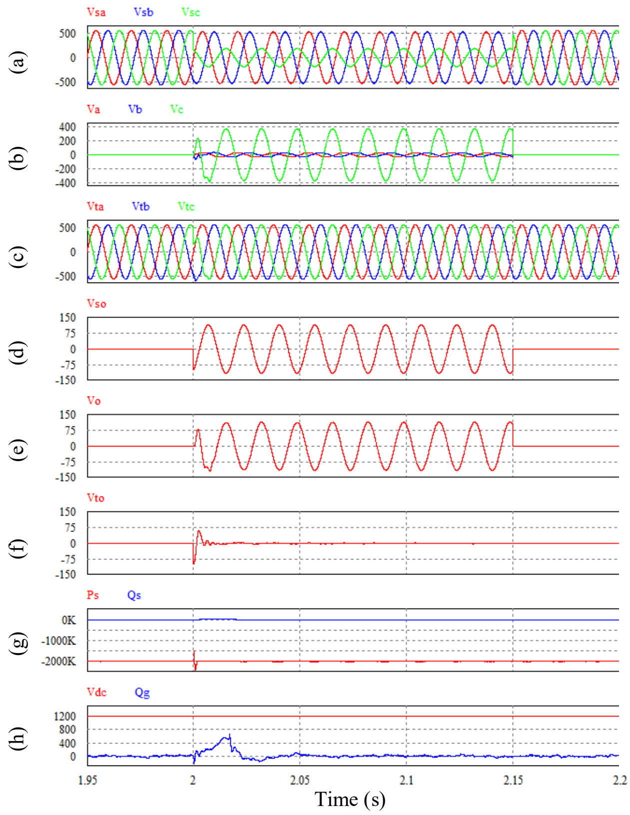

Fig. 4 The simulation results of controlling zero sequence component in DVR for compensating unbalanced voltage dip of DFIG.
(a) supply voltages; (b) compensating voltages of DVR; (c) terminal voltages of DFIG system; (d), (e) and (f) zero sequence components of supply voltages, compensating voltages, and terminal voltages; (g) active and reactive power of DFIG; (h) dc-link voltage and reactive power from grid side converter.

$$V_o = \frac{1}{3}\left(V_a + V_b + V_c\right) \tag{5}$$

In proposed control method, the compensating voltages are controlled in stationary frame by using proportional-resonant controllers. But three-phase voltages are not transformed into αβ-frame, it is controlled directly in abc-frame. The three-phase voltages are controlled independently each other as depicted in Fig. 3. Thus, the sum of the three-phase compensating voltages cannot be zero. This means that zero sequence component can be eliminated from restored voltages with proposed control method.

2.3 Simulation results

Simulation results are carried out by using Psim simulation program for a 2 MW DFIG wind turbine system and a DVR as analyzed in Subsections 2.1 and 2.2. The DFIG parameters are given in TABLE I. The stator active power is controlled at 2 MW. The switching frequency of the DVR is 5 kHz. The injection transformer turn ratio is 1:1. The unbalanced grid voltage dip is appeared at 2 s and removed at 2.15 s. The operation of DVR for compensating unbalanced voltage dips, which contain zero sequence component, and the operation of DFIG are presented in Fig. 4.

The unbalanced voltage dips and its zero sequence component are shown in Fig. 4 (a), (d). By applying the proposed control method, the DVR have ability to compensate for unbalanced voltage dip containing zero sequence component as depicted in Fig. 4 (b), (e). As a resulted, the terminal voltages are restored (Fig. 4 (c)) and almost zero sequence component is eliminated (Fig. 4 (f)). Consequently, the DFIG can operate normally under unbalanced voltage dips as shown in Fig. 4 (g)-(h).

3. Conclusion

The application of DVR for compensating unbalanced voltage dips of DFIG is investigated. The compensating voltages of DVR depend on the voltage dips and on the influence of the zero sequence components. With the proposed control method in abc-frame, the DVR can compensate fully for zero sequence component during unbalanced voltage dip faults. Consequently, the restored voltages are almost balance and DFIG can operate normally under faults. The simulation results confirm the effectiveness of the proposed control method.

TABLE I. SIMULATION PARAMETERS OF 2 MW DFIG

Rated power	2 MW
Stator voltage (phase-to-phase, rms)	690 V
Stator voltage frequency	60 Hz
Stator resistance	1.1616 mΩ
Rotor resistance	1.307 mΩ
Stator leakage inductance	0.05835 mH
Rotor leakage inductance	0.06286 mH
Magnetizing inductance	2.496 mH

Reference

[1] H. Awad, J. Svensson, M. Bollen, "Mitigation of Unbalanced Voltage Dips Using Static Series Ccompensator," IEEE Trans. Power Electronics, Vol. 19, No. 3, pp. 837-846, May 2004.

[2] C. Wessels and F. Fuchs, "High Voltage Ride Through with Facts for DFIG Based Wind Turbines," in Proc. 13th Eur. Conf. Power Electron. Appl. (EPE), pp. 1–10, Sep. 2009.

[3] D. M. Vilathgamuwa and H. M. Wijekoon, "Mitigating Zero Sequence Effects in Dynamic Voltage Restorers", Power Electronics Specialists Conference, pp. 3079-3085, June 2007.