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A LOW-VOLTAGE RIDE-THROUGH TECHNIQUE FOR GRID-CONNECTED CONVERTERS OF PHOTOVOLTAIC SYSTEM USING CURRENT INJECTION METHOD

Sukhbir*[1], Pardeep[2] & Sombir[3]
*1,2&3EE, Ganga Technical Campus Bahadurgarh, India

ABSTRACT

With more and more distributed energy resources (DERs) being installed, the utility requires these generation systems and their interface converters to remain grid connected during voltage sags to ensure the operating stability of the ac power system. These low-voltage ride-through (LVRT) requirements also suggest that the DER generation system injects real power and reactive power to support grid voltages. In this paper, a positive-and negative-sequence current injection method is proposed to meet the LVRT requirement. The risk of overcurrent during the LVRT operation is reduced by the use of method of current injection by using predefined ampere constraint. Operating principle and control methods are defined and analyzed. The results of the paper are validated and explained in the paper. The proposed method is compared with the other technique of LVRT.

Keywords: *Distributed generation resources (DERs), grid connected converter, low-voltage ride-through (LVRT), reactive power.*

I. INTRODUCTION

Distributed energy resources (DERs) have become more important recently as a critical tool for reducing CO2 emissions. As an increasing number of DERs being connected to the grid through interface converters, their dynamic behaviors are critical to the stability of the ac power system. For example, the grid connection requirement [1]–[6] often demands low-voltage ride-through (LVRT) capability on wind power systems. Fig. 1 shows the voltage profiles which the wind-power converter must sustain in various grid codes. Grid codes also demand reactive current injection during a fault to support grid stability. E.ON [1] requires 1.0 p.u. of reactive current as the sag depth reaches 50% as shown in Fig. 2. Some grid codes also require real power support during a fault [5]–[7]. Japan [8] requires photovoltaic converters to remain connected during grid voltage irregularities.

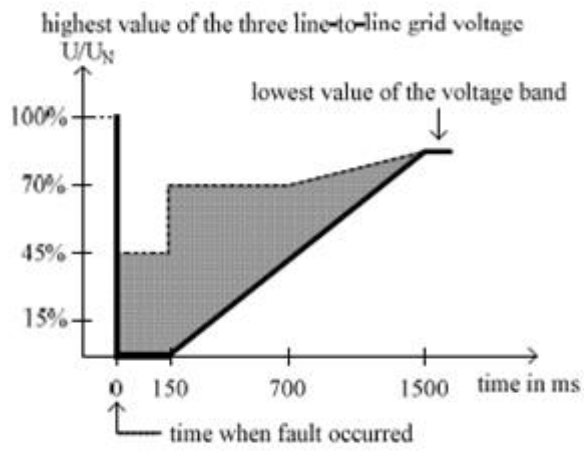

fig 1: Voltage limit of LVRT requirement

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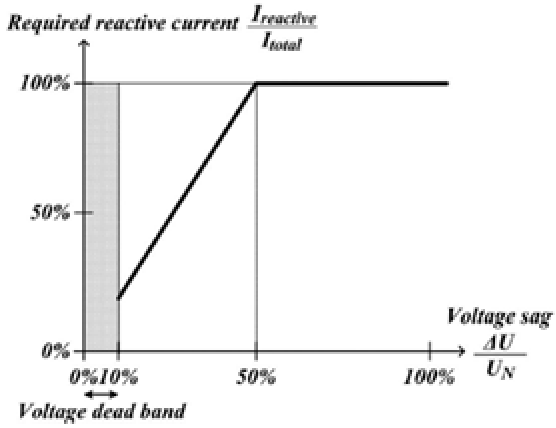

Fig:2 Required reactive current of the E.ON LVRT requirement

This paper proposes an LVRT method to provide the required *real power* and *reactive current* without exceeding the ampere limit of grid-connected interface converters. This method consists of a positive- and negative-sequence current compensation control for the grid-connected converter to support ac grid voltages during the fault and to meet the LVRT requirement. Various control methods, such as vector current controller with feed forward (VCCF) of negative-sequence grid voltage and dual vector current controllers (DVCCs), have been presented in the past [9]–[11]. These methods can produce the required converter current to meet the LVRT requirement, but the unbalanced and decreased grid voltages may easily lead to excessively high current stress on the grid-connected converter as shown in [9]. The DVCC methods inject some negative sequence current on top of the positive-sequence current to reduce the ripple power of twice the grid frequency, thus resulting in high peak current, which risks triggering the converter's overcurrent protection, and fail the LVRT requirement. In some converters, the pulse width modulation (PWM) pulse patterns are modified, or simply turned off, to avoid overcurrent in disregard of the current command, but this approach results in distortion of the current waveforms. The VCCF method generates only the positive-sequence reactive current; the risk of excessively high current is lower if properly controlled. However, the negative-sequence voltage due to the fault remains not attended. Significant torsional stress on turbine generators due to line fault and the resulting negative-sequence current has been reported [12]–[15]. Thus, in addition to the typical positive sequence reactive current injection, this paper proposes a negative-sequence reactive current compensation during the LVRT operation to mitigate the unbalanced grid voltages. By taking into account both the positive- and the negative-sequence reactive currents, the proposed method can inject the real power and the reactive current demanded by grid codes and alleviates the grid voltage imbalance without exceeding the peak current limit of the grid-connected converter.

II. OPERATION PRINCIPLES OF THE PROPOSED CONTROL METHOD

To meet the LVRT requirement, the proposed method injects the real power and the required reactive current in both the positive- and the negative-sequence components. The compensation of the proposed reactive current injection method reduces the negative-sequence voltage component while boosting the positive-sequence voltage component. Thus, the grid voltage imbalance can be trimmed down. The proposed method also adjusts the level of positive- and negative-sequence reactive currents so that a predefined ampere constraint of the converter is not exceeded; thus, the risk of overcurrent tripping of the converter can be greatly reduced.

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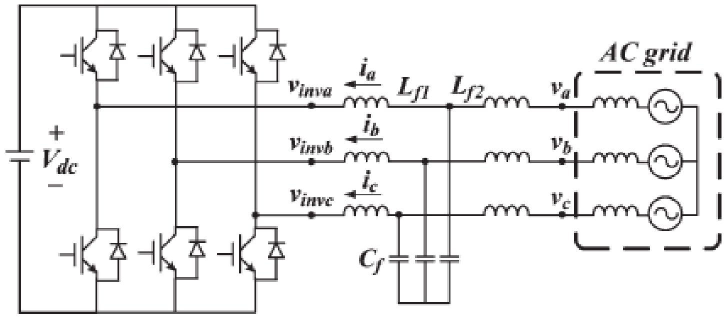

Fig3: System configuration

III. CONVERTER VOLTAGES AND CURRENTS

The system configuration of the converter being connected to the grid is shown in Fig. 3. During the LVRT operation, the power produced by the renewable source needs to be curtailed or redirected so that the grid-connected converter can utilize its capacity to perform its LVRT function. For example, in a wind power system, blade pitch control, energy-storage devices, and active crowbars have been presented to deal with the output power of the wind generator during LVRT [16]–[18]. In this paper, the converter dc bus is supported by a dc source fortesting. Fig. 4 shows the control block diagram of the proposed method. Detailed explanations are given as follows.The grid voltages become unbalanced as the fault occurs. The proposed method produces both positive- and negative sequence currents to meet the LVRT requirement. The grid voltages are expressed as in

$$Va = Vp\cos(wt + \theta 1) + Vn\cos(-wt - \theta 2)$$
$$Vb = Vp\cos\left(wt - \frac{2\pi}{3} + \theta 1\right) + Vn\cos(-wt - \frac{2\pi}{3} + \theta 2)$$
$$Vc = Vp\cos\left(wt + \frac{2\pi}{3} + \theta 1\right) + Vn\cos(-wt + \frac{2\pi}{3} - \theta 2)$$

And the converter currents are expressed as in

$$Ia = Ip\cos(wt + \theta 1 + \theta p) + In\cos(-wt - \theta 2 + \theta n)$$
$$Ib = Ip\cos\left(wt - \frac{2\pi}{3} + \theta 1 + \theta p\right) + In\cos(-wt - \frac{2\pi}{3} + \theta 2 + \theta n)$$
$$Ic = Ip\cos\left(wt + \frac{2\pi}{3} + \theta 1 + \theta p\right) + In\cos(-wt + \frac{2\pi}{3} - \theta 2 + \theta n)$$

Where$Vp$and Vnindicate the positive- and negative-sequence components of the grid voltage, respectively. $Ip$and Inrepresent the positive- and negative-sequence components of the converter current, respectively. $\theta 1$ and $\theta 2$ represent the phase angles of the positive- and the negative-sequence voltages with respect to the reference axis, respectively. $\theta p$and $\theta n$are the phase angles of the positive- and the negative-sequence currents, respectively. The stationary frame representations of the grid voltages and the converter currents are expressed, respectively, as

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & -\frac{1}{3} & -\frac{1}{3} \\ 0 & -\frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where the subscript α, β indicates the stationary reference frame axes.

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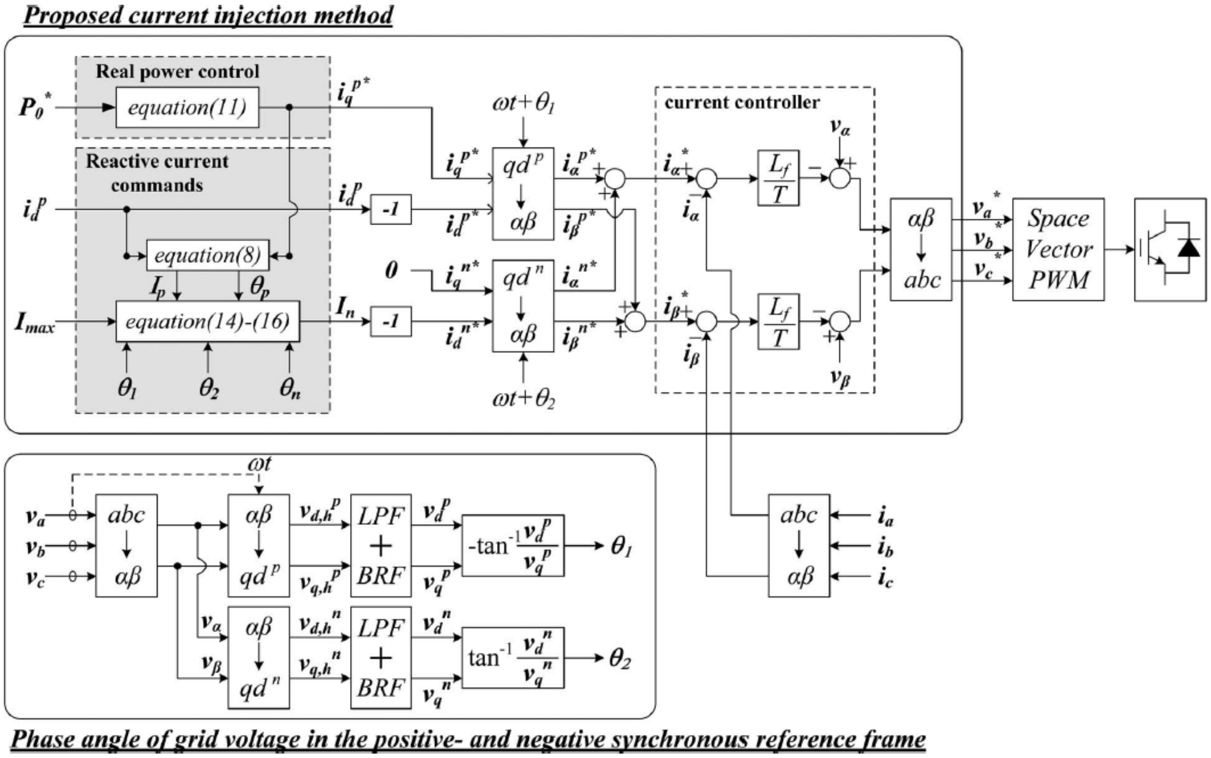

Fig:4 Control block diagram of the proposed method

To meet the grid code requirement, the proposed method produces real power injection with the positive-sequence current and reactive current injection with both positive- and negative sequence currents. The proposed method intends to inject the positive- and negative-sequence currents to meet the LVRT requirement and to reduce grid voltage imbalance. The reactive current injection techniques have been widely applied to the static VAR compensator and static synchronous compensator systems [20]–[22]. The voltage can be supported by drawingthe capacitive reactive power, and the voltage can be reduced by drawing the inductive reactive power. Moreover, the proposed method also generates the current command to accomplish these functionalities without exceeding a predefined ampere constraint. The details about the proposed real power control and the reactive current injection control without exceeding the predefined ampere constraint are explained in the following.

IV. REAL POWER CONTROL

Grid codes may require real power injection during LVRT. The real power of the converter can be expressed as in

$$P = \frac{3}{2}(v_q^p i_q^p + v_d^p i_d^p)$$

by using the instantaneous power theory [23], [24]. Note that the negative-sequence current of the converter is only for reactive current injection; therefore, it does not contribute any real power.

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V. PROPOSED REACTIVE CURRENT INJECTION

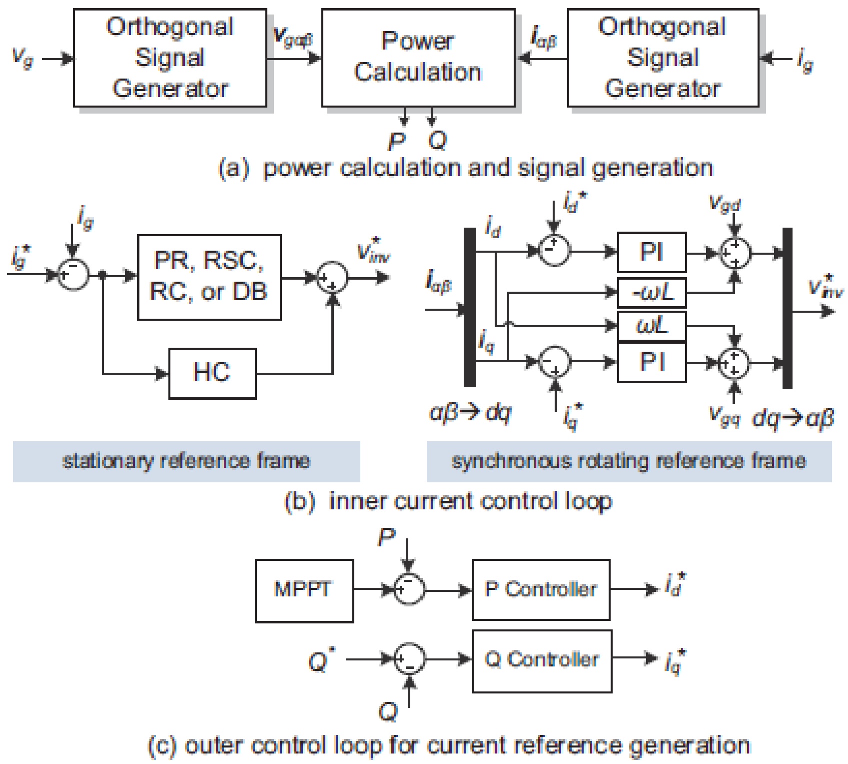

Fig5: Implementation of current control loop in single phase single stage systems in different reference frame

For the current control loop, as detailed in Fig. 5, the existing control methods, such as Proportional Resonant (PR), Resonant Control (RSC), Repetitive Controller (RC), and Deadbeat Controller (DB) can be adopted directly, since they are capable to track sinusoidal signals without steady-state errors [14], [17], [36]-[39]. Further, applying the Park transformation (αβdq) leads to the possibility of Proportional Integral (PI) controllers to regulate the injected current, and afterwards, the modulation reference v* inv can be obtained by means of the inverse Park transformation (dqαβ) [37], [40]. However, as it is shown in Fig. 4, the implementation of a PI-based current control loop in the synchronous rotating reference frame requires a signal generation system, which can produce a quadrature component corresponding to the input, and thus the complexity increases [37]. Since the current control loop is responsible for the power quality, this responsibility should also be effective and valid in the design of current controllers and also the LCL-filter. By introducing Harmonic Compensators (HC) for the controller [13], [14] and adding passive damping for the filter, an enhancement of the current controller tracking performance can be achieved.

VI. CONCLUSION

This paper has presented a new control method for the grid connected converter to meet the LVRT requirement during grid voltage sags. The proposed method injects the real power and the reactive current in both the positive and negative sequences to support the grid voltages during LVRT. An important feature of the proposed method is that a predefined ampere constraint can be imposed while performing the real power and reactive current injection so that the converter output current never exceeds this constraint. This feature reduces the risk of triggering the overcurrent protection while maintaining the current waveform quality; thus, the reliability of the LVRT operation can be improved. Previous LVRT methods, like DVCC1, also produce both positive- and negative-sequence currents but may lead to excessively high peak current. If DVCC1 is scaled back and limits its peak current to *I*max, then its current command becomes one operating point of the proposed method. The proposed method has a unique advantage of offering greater flexibility in the combination of positive- and negative-sequence currents to achieve the desired grid voltage compensation performance in terms of voltage magnitude support or imbalance mitigation.

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