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Distributed generation and the voltage profile on distribution feeders during voltage dips

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ABSTRACT

The presence of distributed generators in the distribution network results in an increase of the voltage magnitude close to these generators, during a fault elsewhere in the distribution system or in the transmission system. This voltage dip mitigation capability of converter-connected distributed generation (DG) units is dependent on the control strategy of the converter. To compare the influence of different types of converter-connected distributed generators on the voltage profile along distribution feeders during a fault, the quantity,“voltage ratio” is used. This voltage ratio is obtained by division of the voltage during the voltage dip by the voltage just before the voltage dip. The different converter types are modelled, and the influence on the voltage ratio is analysed.

1. Introduction

Mitigation of power quality issues by using the grid-interfaces of distributed generators is an interesting approach [1,2], especially for mitigating voltage dips. Indeed, with most of the solutions to increase voltage dip immunity at the load side, the converter for the load absorbs additional grid currents from an already weakened grid to maintain the power balance. Therefore, the contribution of distributed generators can make a significant improvement in the residual voltage as experienced by the customer at distribution level.

Distributed generation units coupled to the low-voltage distribution network are mostly based on power-electronic converters. The strategy applied to control these converters determines the interaction of the converters with the utility grid. In this paper the effects of the converter control on the voltage profile of a distribution feeder during grid voltage dips are analysed.

Many commercially available converters and inverters are based on [3–6] to govern how they are operated during different voltage conditions. During most grid voltage dips the converters would be required to drop off-line, and consequently no support to the grid would be present. In the future, automatic tripping of converter-connected distributed generators on every voltage dip will not be acceptable for the system operators. Therefore, the authors have not considered anti-islanding provisions in the studied control algorithms.

The most common control strategies can be classified in three different types: sinewave converters, pure resistive converters and resistive converters with a programmable damping resistance. Sinewave converters are designed to shape the line current as a pure sinewave, whether the input voltage is distorted or not. This control strategy does not contribute to the stability of the utility grid [7]. Purely resistive converters aim to shape the input current proportional to the input voltage, thus obtaining a resistive behavior at the input of the converter [8–10]. When implemented in a converter for grid-connection of DG units, the input resistance of the converter becomes negative. This increases the risk of voltage oscillations of the grid at harmonic frequencies, and may cause instabilities especially when many converters are connected to the same grid [11–13]. Converters with a programmable damping resistance show a resistive input behavior with a harmonic resistance which can be controlled independently of the input resistance for the fundamental, and thus independently of the power level of the converter. Hence, the converter is able to maintain its damping potential over a wide range of power levels. The implementation of this control strategy has been proposed for single-phase ac–dc converters [12,14]. The implementation for three-phase converters was described in [15,16].

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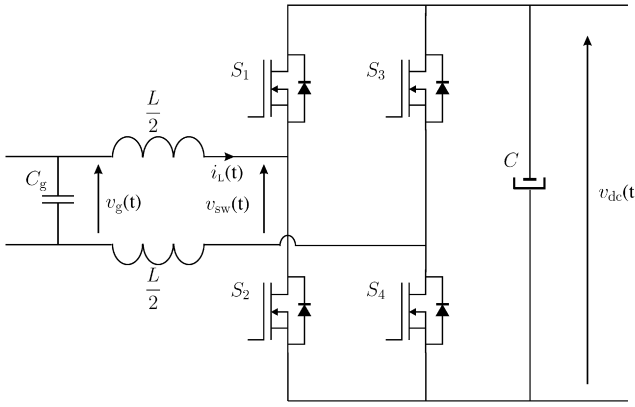

Fig. 1. Topology of the full-bridge bidirectional converter.

The effect of grid voltage dips on converter-based DG is described in [17]. The behavior of the converter during grid voltage dips is mainly dependent on the converter control. The converter with damping resistance has been shown to have a better voltage dip ride-through capability [17]. This controller increases the power injected in the grid during the voltage dip as compared to other controllers. The control scheme is able to increase the grid current immediately where other controllers need some time to react. Thanks to the immediate response, premature shutdown of the converter due to an excessive bus voltage can be avoided.

Loads which are connected to the same terminals as the converter-based DG unit will experience an increased residual voltage at the DG terminals, thanks to the immediate increase of the grid current of the damping converter [18]. Obviously, the residual voltage at all equipment terminals along the distribution feeder will be influenced by the type of control and the location of the distributed generator. In this paper the influence of distributed generators on the voltage profile along distribution feeders during voltage dips is analysed. Methods to analyse the voltage profile are presented.

2. Control strategy

The topology of the single-phase full-bridge ac–dc bidirectional converter is depicted in Fig. 1. The converter consists of an EMI-filter (represented by the capacitor C_g) on the ac-side of the converter, and a boost-type full-bridge converter with two input inductors $L/2$, switches S_1 to S_4, and a buffer capacitor C at the dc-side of the converter. The converter is controlled by means of a digital signal processor (DSP).

The measurements necessary for the control of the converter are the inductor current i_L, grid voltage v_g and bus voltage v_{dc}. These analog variables are converted into digital quantities and are used by the digital controller to calculate the duty-ratio d. The PWM signals are calculated on the basis of this duty-ratio and are presented to the switches of the full-bridge converter.

Most commercially available grid-connected converters use a phase locked loop (PLL) and try to shape the injected line currents as perfect sinewaves [19]. The corresponding control algorithm is depicted in Fig. 2 (black lines only). We will refer to this type of converters as sinewave converters.

The control scheme depicted in black uses two controllers: a bus voltage controller and an inductor current controller. The bus voltage controller maintains a constant bus voltage by changing the value of the fundamental input conductance g. This prescribes the amplitude of the desired inductor current i_L^* and thus the amount of fundamental power exchanged with the grid. The reference value for the fundamental inductor current $i_{L,1}^*$ is the product of the emulated fundamental conductance g and a sinusoidal reference signal $V_g^{\text{nom}}\ \sin(\theta_{\text{PLL}})$:

$$i_L^* = i_{L,1}^* = gV_g^{\text{nom}}\ \sin(\theta_{\text{PLL}}). \tag{1}$$

The phase θ_{PLL} of the sinusoidal reference signal is locked to the phase of the fundamental component of the mains voltage by using a standard phase locked loop.

The control strategy with damping resistance is based on the same operation principle. However, an extra signal is added to the reference value for the inductor current i_L^* of (1):

$$i_L^* = i_{L,1}^* + i_{L,d}^* = gV_g^{\text{nom}}\ \sin(\theta_{\text{PLL}}) + g_h(v_g - V_g^{\text{nom}}\ \sin(\theta_{\text{PLL}})). \tag{2}$$

The last term of (2) is represented in gray in Fig. 2. This term represents the instantaneous reaction of the converter on every deviation of the grid voltage v_g from its steady-state value $V_g^{\text{nom}}\sin(\theta_{\text{PLL}})$. The current originating from voltage disturbances is determined by the programmable damping resistance $1/g_h$.

To obtain a resistive converter behavior, g_h is set equal to g, resulting in:

$$i_L^* = gv_g. \tag{3}$$

All above-mentioned control strategies are power factor correction algorithms. The converters only inject active power into the utility network in normal operation.

Based on Eqs. (1)–(3) we can predict the behavior of the different converter types during grid disturbances. Sinusoidal converters are controlled based on (1), and consequently, they will not react to any deviation of the grid voltage v_g, as the set value i_L^* is not based on a measurement of v_g. Damping converters are controlled based on (2). The grid current will thus react to deviations of the grid voltage v_g considering the second term of (2). During a voltage dip, the rms-value of v_g will drop, resulting in the injection of an additional fundamental current component in the grid. Damping converters will thus show an increased rms-value of the grid current during voltage dips. Purely resistive converters, obtained by implementing (3), will also react to voltage dips as the rms-value of the grid current is proportional to the rms-value of the grid voltage. Therefore purely resistive converters will show a decreased rms-value of the grid current during voltage dips.

Based on these reactions, we can also predict the support given to the utility during voltages dips. The voltage profile along distribution feeders is determined by the voltage at the primary of the distribution transformer and by the current flow along the feeder. During voltage dips, this current is changed, firstly due to the change of current absorbed by the loads, and secondly due to the change of current injected by the distributed generators. Regarding the behavior of the current of the different converter types, we can state that the damping converter will perform best, the sinusoidal

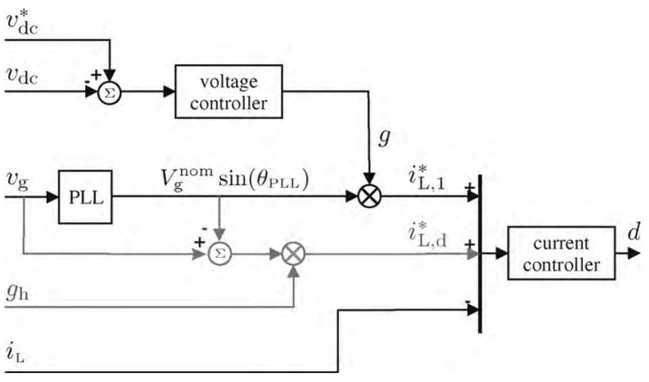

Fig. 2. Control strategy for a grid-connected converter for DG units.