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Optimized secondary control for distributed generation under unbalanced conditions

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Abstract

Control structure have a critical influence on converter-interfaced distributed generations (DG) under unbalanced conditions. In this paper, the relationship between amplitude of active power oscillations and reactive power oscillations is firstly deduced and the hierarchical control of DG is proposed to reduce power oscillations. Current references are generated in the primary control level and active power oscillations can be suppressed by the dual current controller. The secondary control reduces active power and reactive power oscillations by optimal model aiming at minimum amplitude of oscillations. The simulation results show that the proposed scheme with less injecting negative sequence current than traditional control method can effectively suppress oscillations of both active power and reactive power.

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Keywords: distributed generation; secondary control; power oscillations suppression; dual current controller

1. Introduction

Voltage-sourced converter (VSC) now appears to be one of the most promising integration modes of static energy conversion systems for DGs [1]. Most DGs are located at the terminals of distribution network or microgrid where unbalanced conditions exist owing to single-phase loads and asymmetrical faults. Grid imbalance in a three-phase system leads to 100Hz power oscillations. Active power oscillations have negative effects on dc link of converters and reactive power oscillations causing high power loss and over-current stress [2-3]. Consequently, various control structures have been proposed in recent years whose aim is improving VSC operation under unbalanced conditions.

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Control structures have critical influence on the DG's behavior under unbalanced conditions. Notch filters are adopted to separate the components of positive and negative sequences, and the dual PI current controllers are proposed to control positive sequence and negative sequence components respectively [4]. The dc-link voltage ripple and active power oscillations can be suppressed, but reactive power oscillations are significantly amplified and system dynamics are limited by notch filters. Alternatively, delay signal cancellation (DSC) is adopted for real-time symmetrical component extraction which is based on a combination of time-delayed synchronous frame magnitudes and permits a fixed 5 ms delay sequence extraction time [5]. As discussed in [6], it is possible to change the relative amplitudes of oscillating active and reactive power smoothly through an adjustable parameter of current reference.

Previous studies mainly focus on reduction of active power oscillations, but the analytic relationship between active and reactive power oscillations is still unclear. In this paper, the mechanism of power oscillations is revealed from the viewpoint of positive and negative sequence current injection. Furthermore, an optimization model aimed at power oscillations suppression is established, and a secondary control is proposed to simultaneously reduce both active and reactive power oscillations.

2. Mechanism of power oscillations under unbalanced conditions

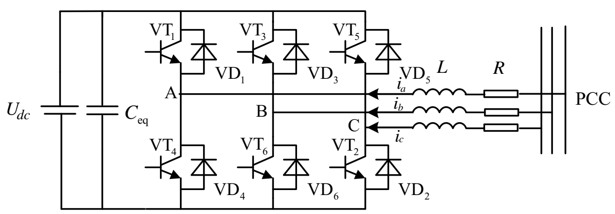

Fig. 1. Equivalent circuit of DG converter

An unbalanced three-phase input voltage { E_a , E_b , E_c } at the PCC causes 100Hz power oscillations, and instantaneous power of a DG can be expressed as

$$P(t) = P_0 + P_{c2}\cos(2\omega t) + P_{s2}\sin(2\omega t) \tag{1}$$

$$Q(t) = Q_0 + Q_{c2}\cos(2\omega t) + Q_{s2}\sin(2\omega t) \tag{2}$$

where P_0 , P_1 , P_{c2} , P_{s2} , Q_{c2} , Q_{s2} can be expressed as

$$\begin{cases} P_0 = E_{d+}^{+}I_{d+}^{+} + E_{q+}^{+}I_{q+}^{+} + E_{d-}^{-}I_{d-}^{-} + E_{q-}^{-}I_{q-}^{-} \\ P_{c2} = E_{d+}^{+}I_{d-}^{-} + E_{q+}^{+}I_{q-}^{-} + E_{d-}^{-}I_{d+}^{+} + E_{q-}^{-}I_{q+}^{+} \\ P_{s2} = E_{d+}^{+}I_{q-}^{-} - E_{q+}^{+}I_{d-}^{-} - E_{d-}^{-}I_{q+}^{+} + E_{q-}^{-}I_{d+}^{+} \end{cases} \tag{3}$$

$$\begin{cases} Q_0 = E_{q+}^{+}I_{d+}^{+} - E_{d+}^{+}I_{q+}^{+} + E_{q-}^{-}I_{d-}^{-} - E_{d-}^{-}I_{q-}^{-} \\ Q_{c2} = E_{q+}^{+}I_{d-}^{-} - E_{d+}^{+}I_{q-}^{-} + E_{q-}^{-}I_{d+}^{+} - E_{d-}^{-}I_{q+}^{+} \\ Q_{s2} = E_{d+}^{+}I_{d-}^{-} + E_{q+}^{+}I_{q-}^{-} - E_{d-}^{-}I_{d+}^{+} - E_{q-}^{-}I_{q+}^{+} \end{cases} \tag{4}$$

Based on (3) and (4), the relationship between active and reactive power oscillations can be derived as followed: