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A direct power control strategy for three level neutral-point-clamped rectifier under unbalanced grid voltage

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ABSTRACT

Direct power control (DPC) strategy has attracted wide attention due to its advantages of simple structure, quick response, strong robustness, and elimination of current regulation loops/PWM blocks. Unfortunately, under unbalanced grid voltage, the conventional DPC (CDPC) scheme with the conventional definitions of active and reactive power cannot work well. In order to solve this problem, a new definition of the active power instead of the conventional one is proposed, discussed and used in this paper. As a result, good performance of the system is achieved and neither complicated calculation of a power compensation term nor positive/negative sequence extraction of grid voltages/currents are required. Then, a switching table based DPC strategy is designed based on the new definition of active power and conventional definition of reactive power. The corresponding switching table is suitable to achieve constant active power, constant reactive power and sinusoidal grid currents with very low total harmonic distortions (THDs). Simulation results are presented to confirm the theoretical study and the effectiveness of the proposed DPC with the new definition of active power (DPC-NP). The performance of the proposed DPC-NP is compared with that of the CDPC and that of the DPC with a new definition of reactive power (DPC-NQ).

1. Introduction

Recently, the use of three-level neutral-point-clamped (NPC) converters [1–3] (see Fig. 1) has increased rapidly due to their advantages of low total harmonic distortion (THD) of the input currents, low du/dt, low switching voltage stress, etc. Compared to the conventional two level topology, the three-level NPC topology provides important advantages in high-power applications. Unfortunately, some inherent problems still exist when the three-level NPC converters are used (e.g. the voltage drifts and voltage ripples of the neutral-point). As a result, its practical application is limited. Therefore, several studies have been conducted to assure the balancing of neutral-point potential, which are software based [4] and hardware modification based [5] methods.

Generally, direct power control (DPC) [6–9] and voltage oriented control (VOC) [10–12] are considered as high-performance control strategies for PWM ac/dc converters. The former (VOC) was developed based on the well-known *field oriented control* (FOC); whilst the latter has the similar properties of *direct torque control* (DTC) [13] for AC drives. In VOC, both active and reactive power components in synchronous frame are obtained by decomposing the grid currents. Through inner current loops using PI controller, the active and reactive power can be regulated. Several VOC strategies have been introduced in the literature to cope with the voltage unbalanced [14–22]. In [14], constant active power is achieved by deriving and regulating the positive- and negative-sequence components of grid currents in the synchronous reference frame [15,16]. However, the use of several PI controllers and the extraction of positive- and negative-sequence components significantly increases the computational burden and tuning efforts. In [17], a dual-frequency resonant compensator and PI regulator were employed to enhance the performance of the control system under unbalanced and distorted grid voltages for doubly-fed induction generators (DFIGs) in variable-speed wind turbine applications. However, due to the sequence decomposition of voltage and current, the time delay and control error in VOC are inevitable. Additionally, the reference current computa-

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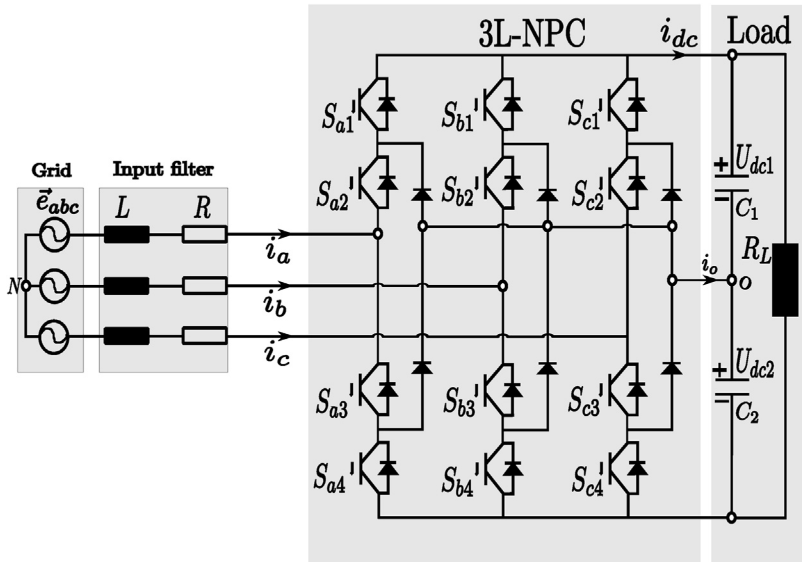

Fig. 1. Topology of the three-level NPC rectifier.

tion for different control targets is also complicated. Hence, to reduce the control complexity of dual current controller, a number of improved methods have been presented in the literature using PI plus resonant and vector PI controller (see e.g. [18–21]). Unfortunately, the extraction of positive- and negative-sequence components of grid voltages is still required. In [22], a new definition of reactive power (proposed in [23]) is investigated in VOC strategy, sinusoidal input current and accurate regulation of DC-voltage are achieved. However, positive- and negative-sequence extraction of both grid voltage/currents and complicated calculations of current reference are not required any more [24].

Various new methods have been presented in the literature to further improve the steady-state performance of the DPC [25–33], like replacing the conventional two-level hysteresis comparators by multi-level ones (see e.g. [25–28]); using of a modulation stage (see e.g. [29,30]); employing of *predictive algorithm* instead of the switching table (see e.g. [31–33]). However, only a few publications consider the operation under unbalanced grid voltages [34,35]. Unbalanced grid voltage has already been a very common phenomenon, which can be caused by, e.g. non-ideal three-phase load, asymmetry faults, large capacity single-phase load, asymmetry of power transmission system, etc. In [34], by adding the distorted terms into the power references, three different specialized control targets under unbalanced grid conditions can be achieved in LUT based DPC, the control targets are no negative sequence current, smooth active power, and smooth reactive power. However, synchronous transformation, extraction of both positive/ negative components of grid voltage and current are needed. A simplified power compensation block is proposed in [35], where the negative sequence current is not required and three different targets are implemented. Unfortunately, the extraction of the positive- and negative-sequence components of grid voltages and the positive-sequence component of grid currents are required. As a result, the control complexity and computational burden is increased. To entirely eliminate the sequence decomposition and keep the simplicity of DPC scheme as far as possible, the authors in [36] combines the merits of DPC and the new definition of instantaneous reactive power, taking the active power and new reactive power as control variables, which is more suitable for unbalanced grid voltages than the conventional reactive power definition. To simplify the calculation process, DPC with this new definition of the reactive power for two-level voltage source converter based on $\alpha\beta$ frame instead of *dq* frame was presented in [37]. However, here is the room for further improvement.

In this paper, a DPC with *a new definition* of instantaneous active power (DPC-NP) expressed in the *dq* reference frame for three-level NPC rectifier under unbalanced grid voltages is proposed. By using this new definition of active power instead of conventional one under unbalanced grid voltage, good performance of the DPC scheme is achieved and the decoupling process of positive and negative sequences are not required. As a result, reducing the computational burden and simplifying the control structure. The proposed DPC strategy is much simpler in structure, in comparison with the conventional DPC (CDPC) solutions and the DPC scheme with the new definition of the reactive power (DPC-NQ) that presented in [37]. Furthermore, no compensation block or calculations of the current references are required. The effectiveness of proposed DPC is validated by extensive simulation data in different scenarios. Its performance is compared with that of *both* CDPC *and* DPC-NQ schemes. The results illustrate the superior performance of proposed DPC-NP in comparison with CPDP and DPC-NQ.

2. DPC of three-level NPC rectifier

In this section, the system description and modeling of the underlying three-level NPC power converter is presented.

2.1. Topology and mathematical modeling of the three-level NPC rectifier

The basic topology of a three-level NPC rectifier is shown in Fig. 1, where, S_{in} (n = 1, 2, 3, 4 and i = a, b, c) are the 12 semiconductor switches of the rectifier, C_1 and C_2 are capacitors in dc-bus and L, R represent inductance and resistance of the input filter, respectively. e_i, i_i and u_i (i = a, b, c) are the three-phase grid voltages, currents and ac-side voltages of rectifier, respectively. U_{dc1} and U_{dc2} are the voltages of C_1 and C_2, respectively. i_0 is the current of neutral point.

The mathematical model of three-level NPC rectifier in the stationary reference frame $\alpha\beta$ can be expressed as follows [36]:

$$\frac{di_\alpha}{dt} = \frac{1}{L}(e_\alpha - u_\alpha - Ri_\alpha) \quad (1)$$