A Dual Buck-Boost AC/DC Converter for DC Nano--Grid with Three Terminal Outputs

Weimin Wu, Houqing Wang, Yuan Liu, Min Huang, and Frede Blaabjerg, *Fellow,IEEE*

***Abstract*—Due to the widely used DC characterized loads and more distributed power generation sources, the DC Nano-grid becomes more and more popular and it is seen as an alternative to the AC-grid. For safety considerations, the DC Nano-grid should provide reliable grounding for the residential loads like the low voltage AC power system. There are three typical grounding configurations for a DC Nano-grid, including the united grounding, the unidirectional grounding and the virtual isolated grounding. Each grounding configuration has its own specifications to AC/DC converters. In this letter, a dual Buck-Boost AC/DC converter for use in the united grounding configuration based DC Nano-grid with three terminal outputs is proposed. The working principle of this converter is presented in details through analyzing the equivalent circuits. Experiments are carried out to verify the theoretical analysis.**

***Index Terms*—DC Nano-grid, Grounding, AC/DC Converter, Buck- Boost.**

I. INTRODUCTION

THE distributed power generation is becoming more and more attractive due to the long term lack of energy and the environmental problems caused by the fossil energy. A large number of distributed generation systems, like photovoltaic systems, are today connected into the AC power system, where they can cause problems like voltage rise and also issue related to protection [1]. Further, more and more loads show DC characteristics, for example, LED lightings, computer power supplies, and also variable-frequency techniques based household electrical appliances. The DC Nano-grid may be a good solution to solve the voltage rise and protection problem of the conventional AC power system and can dismiss the traditional AC/DC converters for DC characterized loads, which may result in reduced power losses and material savings [2].

Recently, research on DC Nano-grid gets of more and more concern [1]-[13], especially for the control of AC/DC topologies [7]-[11], which are the connections between the DC Nano-grid and the traditional AC power system. It should be pointed out, when designing the AC/DC converters for DC Nano-grids, the grounding configuration needs to be addressed [12]-[13], since it determines the costs, the flexibility of the installation and also the efficiency of DC Nano-grid system.

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This letter analyzes first three grounding configurations of the DC Nano-grid. Then, a dual Buck-Boost AC/DC converter is proposed, which will facilitate the applications of the DC Nano-grid with three terminal outputs. Also, theoretical analysis of the proposed converter will be given as well as experimental verifications are carried out. Finally, conclusions are drawn.

II. TYPICAL GROUNDING CONFIGURATIONS FOR RESIDENTIAL DC NANO-GRID APPLICATIONS

In order to ensure the safety in the grid, most of household appliances are required to be connected with ground line, so in a DC Nano-grid, like in a low voltage AC grid, ground line should be provided [12]-[13]. There are three basic grounding configurations, which include the united grounding, the unidirectional grounding and the virtual isolated grounding. They will be explained in the following.

A. United grounding configuration

In this configuration, the AC low power system and the DC Nano-grid use the same ground line. Fig. 1 shows a typical AC/DC converter connection.

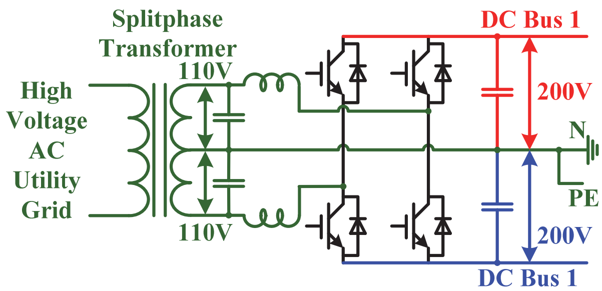

Fig. 1. Typical AC/DC converter for the united grounding configuration based DC micro grid system.

The advantage of the united grounding configuration is that the DC Nano-grid can easily be installed into the original low voltage AC power grid to form a hybrid power system. The disadvantage is that due to the low voltage devices, most of the original low voltage AC power systems cannot adopt this configuration and share the same ground line directly with a DC Nano-grid, if no special or complicated AC/DC converters are adopted. At the same time, the DC Nano-grid has to adopt a bipolar voltage structure with three terminal outputs [1], [10].

B. Unidirectional grounding configuration

As described above, due to the low voltage limit of the devices, it is difficult for the DC Nano-grid to use the same ground line of the low voltage AC power system. Many papers are considering the unidirectional grounding configuration to construct a DC Nano-grid [1], [10], [11].

Fig. 2 shows a unidirectional grounding configuration based DC Nano-grid with double DC bus and the grounding. In this configuration, the DC Nano-grid absorbs the power

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from the high voltage AC utility grid through a step down transformer, which works like an isolated transformer.

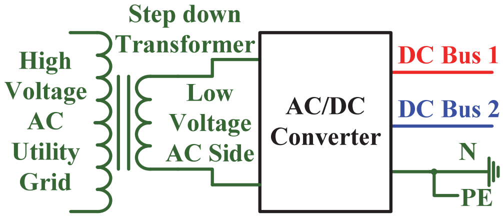


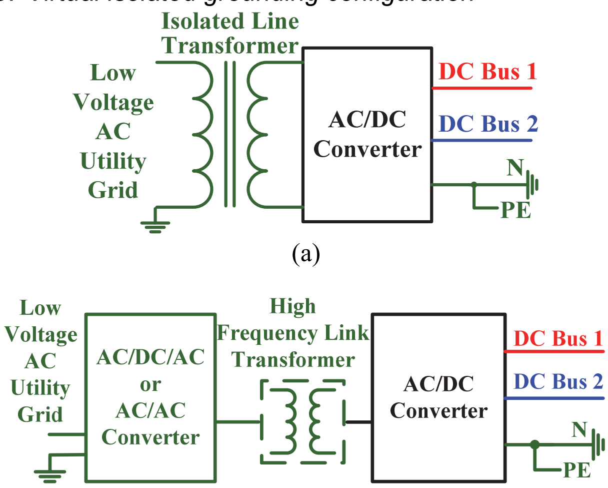
Fig. 2. Unidirectional grounding structure of DC Nano-grid.

Since the step down transformer offers a suitable low voltage for the DC Nano-grid, this AC voltage is generally lower than the standard AC voltage. For example, a three-phase step down transformer may output a 200 V phase to phase voltage rather than the standardized 380 V voltage.

The AC/DC converter transfers the AC power into the DC power as the required DC voltage output and power rating. For example, the DC Nano-grid can be a single DC bus based system [2],[8],[11] or a double DC bus [1],[10] system.

The advantage of the unidirectional grounding configuration is that the AC/DC converter can use simple structure-converters like the two-level three-phase converter [4] or the three-level three-phase converter [10] or even other [1]. The disadvantage of this configuration is that the output of the step down transformer cannot be connected with other low voltage AC residential loads directly.

C. Virtual isolated grounding configuration



(b)

Fig. 3. Virtual isolated grounding structure (a) using line frequency transformer [2],[14], (b) using high frequency link transformer [9].

As mentioned in Part A and Part B, it is no easy to realize the hybrid AC and DC grid system with the same ground line due to the reason of the low voltage devices. So the virtual isolated grounding configuration was proposed [2], [9],[14] which has two basic methods as shown in Fig. 3 with different type of transformers.

Fig. 3(a) shows the virtual isolated grounding configuration using line transformer [2],[14]. This method is similar to the unidirectional grounding configuration, while the transformer is connected with the low voltage AC power system instead of the high voltage AC power system.

Fig. 3(b) shows the virtual isolated grounding configuration using high frequency link transformer [9]. Different from the method shown in Fig.3 (a), the high frequency link transformer is used and two converters are adopted to transfer the energy. Due to an improved efficiency of the converter, the high frequency link transformer based method will be more attractive than the line frequency transformer system.

The advantage of the virtual isolated grounding configuration is that it is very flexible to construct the DC Nano-grid as required. The disadvantage of the virtual isolated grounding configuration lies in the extra power losses brought by the additional transformer together with the possible more converters to be used.

In theory, compared with the AC micro-grid, the DC Nano-grid can save more material and become more efficient due to the fact that less energy conversions are needed. However, as analyzed above, currently, if the DC Nano-grid is connected with the AC power system using the virtual isolated grounding configuration, the efficiency of the system will be reduced, while if using the unidirectional grounding configuration, the flexibility of the DC Nano-grid will be limited. So it is necessary to develop a new type high efficient and low cost AC/DC converter for the united grounding configuration based DC Nano-grid.

III. PROPOSED AC/DC CONVERTER FOR THE UNITED GROUNDING CONFIGURATION BASED DC NANO-GRID

Traditionally, the DC Nano-grid is connected into the AC power system with bi-directional AC-DC converters, which allows extra DC power to be injected back into the AC power system. In some areas, due to the high population density, the distributed power can generally not meet the demand of the local loads, so the connection between the AC power system and the DC Nano-grid can be simplified to be a power factor correction circuit. In [15]-[19], AC/DC converters were reviewed and compared. However, suitable AC/DC converters for the united grounding configuration based DC Nano-grid application were not introduced. In this paper, a new AC/DC converter is proposed.

A. Basic topology

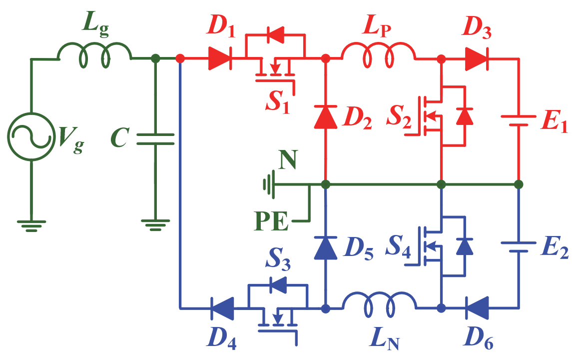


Fig. 4. Proposed AC/DC converter for united grounding configuration based DC Nano-grid.

Fig. 4 shows the proposed AC/DC converter as the connecting converter between three-level voltage DC Nano-grid and the low voltage AC power system. The proposed converter has vertical symmetry structure. During the positive period of the AC voltage, the devices in red work while the devices in black are off. During the negative period

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of the AC voltage, the devices in black work while the devices in red are off.

When the proposed AC/DC converter is adopted, it will be very convenient to connect the DC Nano-grid into most types of current low voltage AC power system, for example, the single-phase 220 V AC power grid, the 110 V AC power grid, and three-phase four-line 380 V AC power grid using three of the same converters. The DC voltage can also be varied in a wide range.

B. Operating modes of the proposed AC/DC converter

1) $|E_1|$ *or* $|E_2| \geq V_{g\_A}$

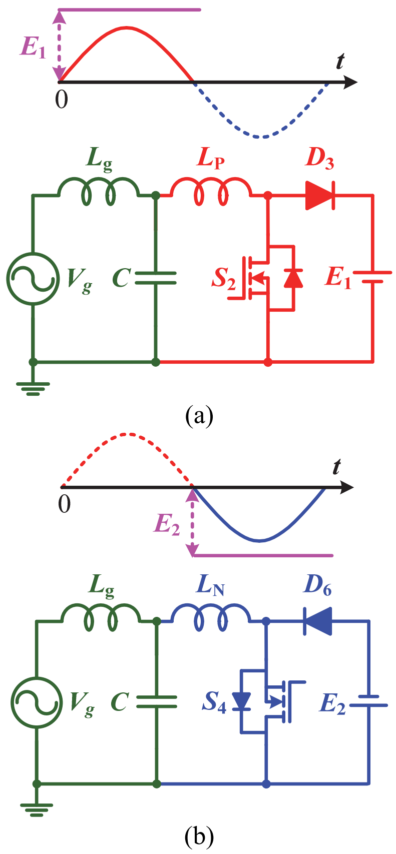

Fig. 5. Equivalent circuits when E_1 and E_2 are higher than the amplitude of the grid voltage and operating in boost mode (a) during the positive period (b) during the negative period.

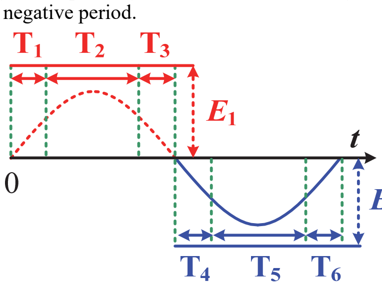

Fig. 6. Working sequence when E_1 and E_2 are lower than the amplitude of the grid voltage.

When the input DC voltage (E_1, or E_2) is larger than the amplitude value of grid voltage, V_{g_A}, the equivalent circuits are as shown in Fig. 5. The inverter works as a pure Boost power factor correction circuit.

2) $|E_1|$ *and* $|E_2| < V_{g\_A}$

When the input DC voltages (E_1, E_2) are lower than the amplitude of grid voltage (V_{g_A}), the control becomes a little bit more complicated. Fig. 6 shows the working sequence of the proposed AC/DC converter, when the amplitude of the input DC voltage is lower than the AC grid voltage, and the sequence can be separated into six parts during a full line frequency period.

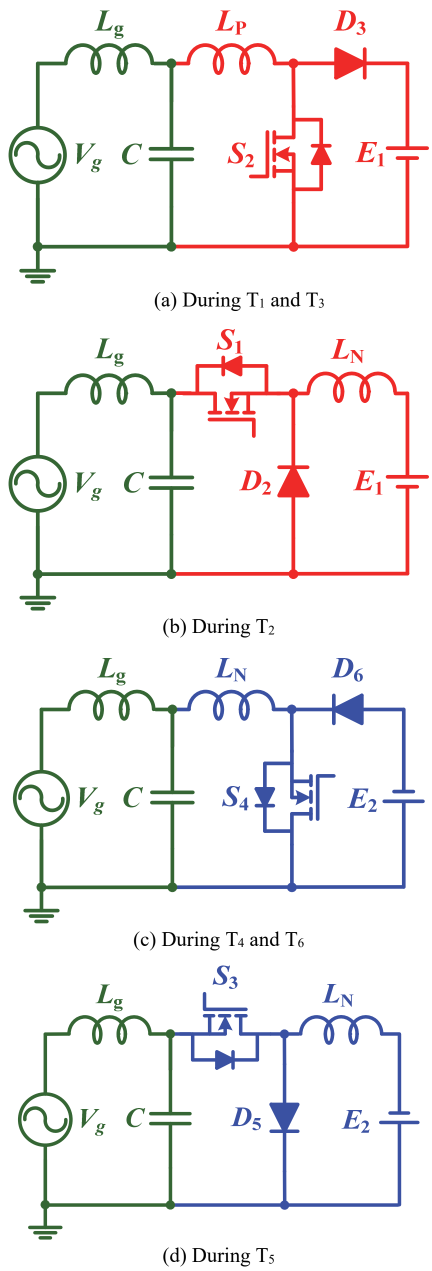

Fig. 7. The equivalent circuits in buck-boost mode as shown in Fig. 6 (a) During T_1 and T_3, (b) During T_2 (c) During T_4 and T_6, (d) During T_5

Fig. 7 shows the equivalent circuits in the Buck-Boost operation. It can be seen than during the different working sequences, it works as a pure Boost or as a pure Buck converter.

IV. Experimental Verification

Experiments on the proposed AC/DC converter are carried out under the AC grid condition of 110 V/ 50 Hz. The parameters of the prototype are listed in Table I.

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TABLE I
DESIGN PARAMETERS OF A 1 KW AC/DC CONVERTER

Para.	L_g	C	L_P, L_N	f_s	E_1, E_2
Units	200 μH	2 μF	400 μH	60 kHz	90V

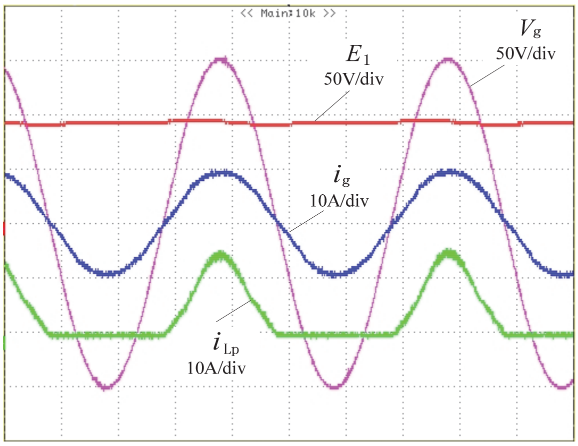

Fig. 8. Measured output DC positive voltage E_1, input AC voltage V_g, inductor current of L_p, and input grid current of i_g.

Fig. 8 shows the input AC grid voltage V_g, output positive DC voltage E_1, the input AC grid current i_{Lg}, and the inductor current of L_N. The experimental results meet the theoretical analysis well.

V. CONCLUSIONS

In residential applications, the DC Nano-grid should provide ground line for safety. The grounding configuration determines the different requirements on the AC/DC converters.

In this letter, three types of the grounding configurations for the DC Nano-grid are summarized. It can be concluded，

1. The united grounding configuration is the most attractive since the DC Nano-grid can be directly connected with the low AC power system using the same ground line, which will strongly address the high efficiency character of the DC Nano-grid. This grounding configuration makes it easy to construct a DC Nano-grid based on the original low voltage AC power system and contributes to the application of the DC Nano-grid. However, suitable AC/DC converters are currently lacking of this grounding configuration.
2. The unidirectional grounding configuration is widely introduced in current DC Nano-grids. It is suitable for construction a new DC Nano-grid alone.
3. Compared with the united and unidirectional grounding configurations, the flexibility of the virtual isolated grounding configuration is good, but it results in reduced efficiency, more materials, and thereby higher costs.

Based on the analysis on the grounding, a dual Buck-Boost AC/DC converter is proposed for the united grounding configuration based DC Nano-grid. The principle of the proposed converter is illustrated using equivalent circuits. Experiments are in good agreement with the theoretical analysis. The proposed AC/DC converter will help to exploit the application of the DC Nano-grid with three terminal outputs.

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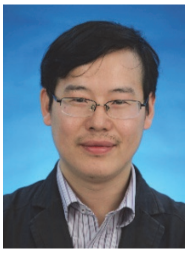

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