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 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.

Manuscript received December 11, 2015; revised May 28, 2016; accepted July 5, 2015.

Weimin Wu, Houqing, Yuan Liu, and Min Huang are with the Research Institute of Electronic Automation of Shanghai Maritime University, Shanghai, 201306, China, phone: 8621-3828-2624; Email: wmwu@shmtu.edu.cn.

Frede Blaabjerg is with the Department of Energy Technology, Aalborg University, Pontoppidanstrade 101, 9220 Aalborg, Denmark. Email: fbl@et.aau.dk.

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.](Image)

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

![Step down Transformer](image)

**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 DC Nano-grid.

**C. Virtual isolated grounding configuration**

![Isolated Line Transformer](image)

**Fig. 3(a). Virtual isolated grounding structure (a) using line frequency transformer [2],[14].**

As mentioned in Part A and Part B, it is not easy to realize the hybrid AC and DC grid system with the same ground line due to the reason of the low voltage devices. 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 frequency 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**

![Proposed AC/DC converter for united grounding configuration based DC Nano-grid](image)

**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...
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 $|E_2| \geq V_{g,A}$

When $E_1$ and $E_2$ are higher than the amplitude of the grid voltage, the equivalent circuits 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 $E_1$ and $E_2$ are lower than the amplitude of the grid voltage, 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.

**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.
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.

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 in 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.

ACKNOWLEDGMENT

This work was partially supported by the Project of Shanghai Pujiang Program under Award 14PJ1404200, the Shuguang Project of Shanghai Municipal Education Commission under Award 14SG43, and the Project of National Science foundation of China (NSFC) under awards 51577114 and 51561165013.

REFERENCES


Weimin Wu received Ph.D. degrees from the College of Electrical Engineering, Zhejiang University, Hangzhou, China, in 2005. He worked as a research engineer in the Delta Power Electronic Center (DPEC), Shanghai, from July, 2005 to June, 2006. Since July, 2006, he has been a Faculty Member at Shanghai Maritime University, where he is currently a Full Professor in Department of Electrical Engineering. He was a Visiting Professor in the Center for Power Electronics Systems (CPES), Virginia Polytechnic Institute and State University, Blacksburg, from Sept. 2008 to March. 2009. From Nov. 2011 to Jan. 2014, he is also a visiting professor in the Department of Energy Technology, working at the Center of Reliable Power Electronics (CORPE). He has coauthored over 80 papers and holds five patents. His areas of interests include power converters for renewable energy systems, power quality, smart grid, and energy storage technology.

Houqing Wang was born in Jiangsu Province, China, in 1991. He received the B.S. degrees in Merchant Maritime College, Shanghai Maritime University, Shanghai, China in 2015. Now he is pursuing the M.S. degrees in Power Electronics and Power Drives, Shanghai Maritime University. His current research interests include digital control technique of power converters, renewable energy generation systems, and active power filters.

Yuan Liu was born in Jiangsu Province, China, in 1990. He received the B.S. degrees in Electrical Engineering and Automation, Nanjing university of Science and Technology, Nanjing, China, in 2013. Now he is pursuing the M.S. degrees in Power Electronics and Power Drives, Shanghai Maritime University, Shanghai, China. His current research interests include digital control technique of power converters and renewable energy generation systems.

Min Huang was born in Hunan, China. She received the B.S. degree from the Department of Electrical Engineering, Shanghai Maritime University, Shanghai, China, and the Ph.D. degree in the Institute of Energy Technology, Aalborg University, Aalborg, Denmark. Now she is an assistant professor of Shanghai Maritime University. Her research interests include power quality, control, and power converters for renewable energy systems.

Frede Blaabjerg (F’03) was with ABB-Scandia, Randers, Denmark, from 1987 to 1988. From 1988 to 1992, he was a Ph.D. Student with Aalborg University, Aalborg, Denmark. He became an Assistant Professor in 1992, an Associate Professor in 1996, and a Full Professor of power electronics and drives in 1998. His current research interests include power electronics and its applications such as in wind turbines, PV systems, reliability, harmonics and adjustable speed drives. He has received 15 IEEE Prize Paper Awards, the IEEE PELS Distinguished Service Award in 2009, the EPE-PEMC Council Award in 2010, the IEEE William E. Newell Power Electronics Award 2014 and the Villum Kann Rasmussen Research Award 2014. He was an Editor-in-Chief of the IEEE TRANSACTIONS ON POWER ELECTRONICS from 2006 to 2012. He is nominated in 2014 by Thomson Reuters to be between the most 250 cited researchers in Engineering in the world.