Design of an Input-Parallel Output-Parallel LLC Resonant DC-DC Converter System for DC Microgrids

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Abstract: Compared with the centralized power system, the distributed modularized power system is composed of several power modules with lower power capacity to provide a totally enough power capacity for the load demand. Therefore, the current stress of the power components in each module can then be reduced, and the flexibility of system setup is also enhanced. However, the parallel-connected power modules in the conventional system are usually controlled to equally share the power flow which would result in lower efficiency in low loading condition. In this study, a modular power conversion system for DC micro grid is developed with 48 V dc low voltage input and 380 V dc high voltage output. However, in the developed system control strategy, the numbers of power modules enabled to share the power flow is decided according to the output power at lower load demand. Finally, three 350 W power modules are constructed and parallel-connected to setup a modular power conversion system. From the experimental results, compared with the conventional system, the efficiency of the developed power system in the light loading condition is greatly improved. The modularized design of the power system can also decrease the power loss ratio to the system capacity.

1. Introduction

Facing the depletion of energy, many countries have conducted research on renewable energy in recent years, hoping to reduce environmental pollution and damage. There are different types of energy, such as wind power and solar power, so the micro-grid system combining different renewable energies has become one of directions of research [1], [2]. Micro-grid is a system consisting of the renewable energy, user load and energy storage system combined into the system and can strengthen the security and reliability of regional power supply. In modern society, most household appliances, solar power generation and power storage systems use DC power supply, and the use of DC power supply can reduce the variables. So the development of decentralized DC micro-grid will become more and more popular.

Because the micro-grids in different areas require different output power, the distributed power system is preferable [3]. This system utilizes a number of small power modules in parallel to supply power to the load, which can effectively reduce the current stress on the power components and reduce the difficulties in the selection of components when designing the circuit.

2. System Structure

The distributed power system presented in this paper has been developed for the distributed micro-power system, its structure shown in Figure 1. The system architecture consists of a full bridge-half bridge LLC resonant DC power converter [4-7], a current feedback circuit, a gate drive circuit and
micro controller, and a voltage feedback circuit and master microcontroller. The system uses the input 48 V DC bus as the input and utilizes the master micro-controller to coordinate the power supply of the decentralized power supply system, to provide a stable voltage in the 380 V DC bus. As shown in the figure, the modular power conversion system is run by multiple power modules in parallel.

![System Architecture Diagram](image)

**Figure 1. System Architecture Diagram**

Figure 2 shows the circuit architecture diagram of a full bridge LLC resonant DC power converter. This circuit consists of a full bridge converter, an LLC resonant circuit, an isolated transformer and a voltage doubling circuit. This architecture uses phase-shift pulse width modulation (PSPWM) [8] to drive switching elements Q₁ to Q₄. Through resonant compensating inductor Lᵣ, resonant electric capacity Cᵣ and transformer magnetizing inductor Lᵣm. Then connecting an isolation transformer with turn ratio of Nₚ: Nₛ, to get boost and the effect of isolating input from output, finally connecting with a voltage doubling circuit composed of a bipolar D₁, D₂ and capacitors C₁, C₂, to rectify the voltage and boost it to 380 VDC.

![Diagram of Circuit Architecture](image)

**Figure 2. Diagram of Circuit Architecture**

### 3. Circuit Analysis

The circuit shown in Figure 3 is the equivalent circuit of LLC resonant circuit. The input of this is square wave Vᵢₙₐc output from the full-bridge converter, which is then resonated by LLC and output as equivalent load Rₑc. The relation of Rₑc is shown as equation (1), where Rₑ is the secondary side output load. The relation of resonant frequency fᵣ is equation (2). The ratio Fₓ between operating frequency fₛ and resonant frequency fᵣ is equation (3). The relation of quality factor Q is equation (4). In addition, the ratio K between total primary inductance and resonant inductance is equation (5). Conducting the impedance analysis based on the equivalent circuit in Figure 3. We find voltage gain is equation (6).

![Equivalent Circuit of LLC Resonant Circuit](image)

**Figure 3. Equivalent circuit of LLC resonant circuit**
Use equation (6) to conduct a numerical analysis, we can obtain the diagram of relation between operating frequencies and resonant frequencies in different quality factors as shown in Figure 4. When the resonant frequency is equal to the operating frequency, the voltage gain is 1.

\[ G = \frac{F_x^2(K-1)}{\sqrt{(K-F_x^2-1)^2 + Q^2F_x^2(K-1)^2(F_x^2-1)^2}} \]  

**Figure 4.** The relationship of Gain and \( F_x \)

4. Experiment result

A decentralized power system is built up for this paper, the physical circuit shown in Figure 5. This system simulates the feasibility of this system using three converters in parallel. The specifications of the converter are 48 V at the input and 380 V/0.92 A (350 W) at the output. The turn ratio of primary side to secondary side of isolation transformer is 1: 4.7. The switching frequency of power switching element is 50 kHz. The three power converters designed for this system are made in the same specification. They transmit current feedback value to the communication connection required by the master controller, connect with one another in parallel for power input and power output, and can operate independently.
Figure 6 shows the comparison between the operating efficiency of using this system strategy and that of three power modules in parallel. As shown in the figure, operating at 175 W of output power, the efficiency may reach up to 91%, 7% higher than three modules operating in parallel. When output power is 350 W, the efficiency of this system is 90.6%, 2.1% higher than three modules operating in parallel. The feasibility of this system can be confirmed by the experimental waveform.

5. Conclusion
This paper shows a decentralized power system that can be applied to the DC micro grid. The system architecture is to modularize the phase-shift full bridge LLC resonant converters and connect the input and output to the two DC bus in parallel. The power switch element the converter has the advantages of zero voltage switching. In addition, the voltage feedback, current feedback and control strategy are used to increase or decrease the number of modules under different output power, to reduce switching loss when the load is light and further enhance the overall system efficiency. On the other hand, the system is able to share the current stress caused by different power modules, to achieve the highest efficiency. This paper shows three 350 W power modules in parallel are developed to simulate the distributed power system with large-capacity. With different loads, the system can be tested and calculated.

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