Research on Harmonic Power Sharing Method Based on Intelligent Matching Virtual Harmonic Impedance

Jiaxiong Zhu, Jiang Qiang, Zhigang Xiao and Chang Feng

School of Physics and Electronic Engineering of Leshan Normal University, Leshan 614004, China
Email: 29265599@qq.com

Abstract. The mismatch between the feeder impedance of each parallel inverter connected to the public AC bus in the microgrid and its rated capacity will cause harmonic circulation in the system. In order to effectively suppress the harmonic circulating current and balance the power distribution among the inverter units, this paper introduces an adaptive virtual harmonic impedance controller in the harmonic domain to reshape the impedance of the system to match the feeder impedance, Dynamically adjust the harmonic current distribution, obtain the modulated wave through the measuring current and voltage double-loop control, and then drive the inverter to operate through the SPWM modulation circuit. MATLAB/Simulink simulation, the results show that the harmonic power distribution method based on virtual intelligent matching harmonic impedance raised in this paper can significantly suppress the harmonic circulating current between parallel inverter systems, and improve the quality of output voltage of parallel inverter systems. The accurate power distribution of the inverter is realized, and performance of inverter in parallel system with a nonlinear load is improved.

1. Introduction

The non-isolated photovoltaic inverter is efficient and low cost, and has been widely used in photovoltaic grid-connected power generation occasions [1]. However, due to inverter line parameters, digital pulse width modulation and other factors, its parallel grid-connected structure has potential problems of high-frequency harmonic circulation and resonance [2], which will increase system losses, affect device life, and produce serious electromagnetic Interference, limiting the increase in system capacity.

For the problem of high-frequency harmonic circulating current, Refs. [3-4] proposes to calculate the harmonic power of each parallel inverter and send it to the central controller. The harmonic power command is calculated and sent to the local controller of each inverter Harmonic current is divided equally. This type of solution is based on the two-layer control of communication. If the communication system fails, it will lose its effectiveness.

Refs. [5-6] proposed a negative virtual impedance method to achieve a reasonable distribution of harmonic power and ensure the quality of the public AC bus voltage. The negative assumed harmonic impedance can offset the pressure drop caused by the resistive component in the line impedance and improve the output voltage quality, but this method requires accurate feeder impedance information. Under normal circumstances, it is difficult to estimate the linear impedance in the power system. If the negative virtual harmonic impedance value is too large, the impedance characteristics of the entire system will be negative, which will cause serious system instability.

This paper introduces an adaptive assumed harmonic impedance controller in the harmonic domain,
reshapes the Assumed equivalent impedance of system in the harmonic domain to match the feeder impedance, dynamically adjusts the harmonic current distribution, and obtains the modulated wave through the measuring current and voltage double-loop. The SPWM modulation circuit drives the inverter to run, and finally achieves the harmonic power sharing of the parallel inverter, which obviously suppresses the harmonic circulation current between the parallel systems of the inverter and improves the quality of the output voltage of the inverters in parallel systems.

2. Analysis of Harmonic Circulating Current of Parallel Inverter

With the development of parallel inverting technology, the capacity of the inverter system can be efficiently changed by investing and cutting out the number of parallel inverters, and the redundancy of the inverter system can be improved. However, if the impedance of the feeder from each inverter to the common AC bus in the parallel system does not match its capacity, the output power will not be evenly distributed among the inverters to form a circulating current, which will overload an inverter and even worse will cause the inverter system to collapse [7].

In the harmonic domain, according to the sinusoidal circuit theory, the inverter is regarded as a short circuit equivalent to its internal resistance, and a nonlinear loads correspond to harmonic current sources. Figure 1 is the equivalent model of circulating current in the harmonic domain of a parallel inverter system with a nonlinear load. In the figure, $I^h$ is the current of a nonlinear load of harmonic, $I^h_{o1}$, $I^h_{o2}$ are the harmonic current components output by the 1 # inverter and 2 # inverter, respectively.

![Figure 1. Harmonic equivalent model of inverter in parallel.](image)

According to the circuit theory, the harmonic current output by the parallel inverter is:

$$I^h_{o1} = \frac{R_{L1} + R_{inv2}}{R_{L1} + R_{inv1} + R_{L2} + R_{inv2}} I^h$$

(1)

$$I^h_{o2} = \frac{R_{L1} + R_{inv1}}{R_{L1} + R_{inv1} + R_{L2} + R_{inv2}} I^h$$

(2)

Generally, the distance between each parallel inverter and the load in the low-voltage microgrid is different. The influence of factors such as system control parameters, dead zones, and filters makes the output impedance of the inverters in parallel systems vary. Therefore, when the system impedance of the inverters in parallel systems is not matched, the inverter with a small system impedance bears more harmonic current than other inverters and forms a harmonic circulation current between the inverters. The size of the harmonic circulating current is related to the impedance difference of the parallel system. The larger the difference, the greater the circulating current.
3. Traditional Harmonic Power Sharing Method
In order to improve the current refining precision of the parallel system and ensure its safety and reliability when powering a non-linear load, a fixed assumed harmonic impedance is added to the harmonic domain [8-10]. The equivalent model is shown in figure 2.

After adding a fixed virtual harmonic impedance, the public AC bus voltage is

\[ u_{pc} = G(s) * u_{ref}^f - R^f * i^f_o - (R^h + R_{VHI}) * i^h_o \]  

where \( u_{ref}^f \) is the reference voltage of inverter fundamental voltage, \( i^f_o \) is the fundamental current in the inverter output current, \( i^h_o \) is the harmonic current in the inverter output current. The inverter output \( i_o \) are \( i^f_o \) and \( i^h_o \), \( G(s) \) is the closed-loop gain controlled by the system.

An excessively large fixed virtual harmonic impedance value \( R_{VHI} \) will cause a severe drop in the voltage of the public AC bus and distortion of the waveform. The harmonic power sharing method based on the assumed Virtual harmonic domain impedance values controller raised in the paper can dynamically adjust the assumed Virtual harmonic domain impedance values \( R_{VHI} \) according to the output harmonic current of each parallel inverter, while improving the accuracy of harmonic power sharing, avoid voltage drop and waveform distortion caused by excessive \( R_{VHI} \).

4. Adaptive Virtual Harmonic Impedance
The paper presents an assumed virtual harmonic domain impedance values method. The core of the controller: detect the harmonic current of the inverter, and calculate the effective value of the current to control the assumed harmonic impedance value, and adaptively compensate the system impedance, thereby improving the accuracy of the harmonic current distribution of the system. Figure 3 shows the structure of an adaptive virtual harmonic impedance controller.

The adaptive virtual harmonic impedance is

\[ R_{VHI}^- = k^h I^h_o \]  

Figure 2. System model of harmonic circulation of adaptive virtual harmonic impedance.

Figure 3. Diagram of adaptive virtual harmonic impedance controller.
Among them, $I^h_o$ is the effective value of the output harmonic inverter current, $k^h$ is the virtual harmonic impedance adjustment coefficient, which directly affects the speed, accuracy and voltage quality of the harmonic current distribution in parallel systems.

Figure 4 is the control modules diagram of inverter system based on adaptive virtual harmonic impedance.

The realization process of harmonic power distribution method based on adaptive assumed harmonic impedance is as follows: The fundamental current $i_o^f$ in the current $i_o$ of the inverter is extracted by the single current detection method by transformation FFT. The harmonic current $i_o^h$ of the inverter is obtained by making a difference between $i_o$ and $i_o^f$, $i_o^h$ multiplies with adaptive virtual harmonic impedance $R_{vHI}$ to obtain harmonic voltage drop $u_{vHI}^h$. Make a difference between voltage $u_{ref}$ and harmonic voltage drop $u_{vHI}^h$ to get output voltage command $u_{ref}$. The output filter inductor current and voltage of the inverter are used as feedback signals, which are controlled by voltage and current double loop to get modulation wave. Finally, the inverter is driven by SPWM modulation circuit.

5. Simulation Verification

The harmonic current balance of the parallel inverter is shown in figure 5. The current sharing control strategy was not added before 0.5s, and the harmonic current sharing strategy of adaptive assumed harmonic impedance control showed in this paper was added at 0.5s. As can be seen in figure 5, with the addition of adaptive virtual harmonic impedance, the harmonic current of inverter and the output current of inverter are basically the same, and the harmonic circulating current is significantly reduced.

Figure 5. Simulation results of adaptive virtual harmonic domain impedance values method.

Figure 6 is the harmonic wave of inverter and the voltage waveform of common connection point.
when the virtual harmonic impedance method with a fixed 1Ω is switched to the adaptive virtual harmonic impedance method. Switching at 1s, it can be seen that after the adaptive virtual harmonic domain impedance values method is enabled, the adaptive assumed harmonic impedance method has less voltage drop than the fixed assumed harmonic impedance method when the circulating current suppression effect is basically the same, THD is reduced from 6.3% to 2.5%, voltage quality is significantly improved. Table 1 shows the simulation of the output voltage amplitude, output voltage THD and harmonic circulating current under different harmonic current sharing strategies.

![Figure 6. Simulation results of different methods switching.](image)

Table 1. Comparison of different harmonic current sharing control.

| Program                        | Output voltage amplitude | The output voltage THD | Harmonic circulation amplitude |
|--------------------------------|--------------------------|------------------------|--------------------------------|
| No harmonic current sharing strategy added | 310V                     | 1.7%                   | 2.2A                           |
| Fixed virtual harmonic impedance strategy | 286V                     | 6.3%                   | 0.4A                           |
| Adaptive virtual harmonic impedance strategy | 305V                     | 2.5%                   | 0.3A                           |

6. Conclusion
Aiming at the fundamental and harmonic circulation problems caused by an imbalance of matching impedance of two parallel three-phase inverter systems with nonlinear loads, the paper proposes a harmonic power sharing method based on adaptive assumed harmonic domain impedance values control, the method adjusts the virtual assumed harmonic impedance in a timely manner according to the effective value of the output harmonic current of each inverter, reshapes the equivalent resistance value of the system in the harmonic domain to achieve matching, and finally achieves harmonic current sharing and suppresses harmonic circulation.

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