Active and Reactive Power Distribution for Cascaded-H-Bridge Microinverters under Island Microgrid

Maohang Qiu, Mengxuan Wei, Shuai Yang, Xiaoyan Liu, and Dong Cao
School of Engineering: Department of Electrical and Computer Engineering
University of Dayton
Dayton, USA
dcao02@udayton.edu

2021 IEEE Energy Conversion Congress and Exposition (ECCE) | 978-1-7281-5135-9/21/$31.00 ©2021 IEEE | DOI: 10.1109/ECCE47101.2021.9595590

***Abstract*— Cascaded-H-Bridge inverter is a good candidate for distribute generators due to the low voltage stress devices required. Power sharing distribution and communication among different microinverter modules are two hot issues that has been solved by inverse-droop method. However, this method can just ensure the power sharing equally among different microinverter modules. In this paper, an improvement power distribution method based on droop control that adapts reactive power to change frequency is proposed. Compared with inverse-droop control method that utlizing power factor as feedback to change frequency, the proposed method can distribute the active and reactive power in a wide range. The feasibility of the proposed control method has been verified by the simulation and hardware experiment results.**

Keywords—Cascaded-H-Bridge (CHB), Distribute Generators (DG), Inverse Droop Control, Reactive Power to Frequency (Q-f)

I. Introduction

Distribute Generator(DG) is widely studied recently for new energy resources application like PV, wind and tidal energy. Much research has been conducted to address the importance of power DG system[1]-[2]. Cascaded-H-Bridge (CHB) Inverter takes the advantage of adapting low voltage stress devices which, as a result, is safer to people. And every H-bridge module (HBM) can be connected to different power source like battery, PV panel to finally simulate the power grid under island mode or transfer energy to power grid under grid-connected mode[3]-[5]. Figure. 1 shows a typical CHB inverter system and it is very easy to be modularized, replaced or maintained due to the same structure of every unit. Each HBM control method can be divided into centralized method and decentralized method. For centralized control method, one master core is needed to calculate phase angle, reactive power, active power and so on while slave cores just need to produce the required output voltage according to information from master core[6]-[7]. For decentralized control method, there are two main issues should be considered: the first one is the synchronization of different inverter modules, and the second one is the power distribution among them due to the different capacities of different power sources. In order to solve the two issues, different methods have been proposed and they can be divided into two kinds by whether using communication among different HBMs. For grid connected decentralized control (GCDC) cascaded inverter, only one module works as current source while other modules work as voltage source is proposed in[8]-[9]. Although the communication parts within different modules are removed, each module must sample grid voltage to get the angle of grid phase. In order to decrease PLL circuits to improve the robustness of the whole system, only one inverter samples grid voltage is proposed in[10]. However, other modules must get the output voltage angle information from the one that samples grid voltage. As a result, the robustness of the whole system is not strengthened. Droop control is commonly adopted due to the excellent reliability and expansibility and the communication can be avoided[11]-[12]. Paper [13]-[16] introduces droop control to cascaded inverter systems to totally remove the PLL circuits and communication parts in GCDC application. As a result, the cost and robustness are strengthened. Although droop control can be adopted into cascaded inverter system, there are some differences when compared with parallel inverter system. For parallel inverter system, active power and reactive power are adopted as feedback to adjust the frequency and value of output voltage. And line impedance will make a big influence on the control strategy. For cascaded inverter system, just one state variable like power factor is adopted as feedback to adjust frequency. Therefore, just one state variable can be controlled precisely. This is also one major issue should be addressed when droop control method is adopted into cascaded inverter.

For island connected decentralized control (ICDC) cascaded inverter, paper [17] adapts high-bandwidth intraconverter communication system to transmit time critical control signals to the module controllers. The control complexity decreases while the hardware cost increases. In fact, communication is not necessary when cascaded inverter works under ICDC mode. Referring to droop control for parallel inverters, the inverse-droop control concept for ICDC is firstly proposed in [18]. It also totally avoids the communication within different inverter modules. However, this method is not suitable for resistance-capacitor load, so paper [19] improves it by adapting power factor as feedback parameter. Although the communication within different inverter modules is saved by utilizing droop control, the active and reactive power can't be freely allocated. In order to solve this problem, an improved method based on inverse-droop control is proposed in this paper.

Section II presents the derivation of control algorithm and power distribution range In section III, the detailed control method is illustrated. In section IV, simulation and prototypes are built to verify the feasibility of proposed method. Finally, section V concludes this paper.

II. Active Power And Reactive Power Control Algorithm

A. Derivation of Control Algorithm

N module CHB inverters in series are shown as Fig. 1 The load impedance is expressed as Z_x. Suppose load Z_x is far greater than line impedance Z_i, and Z_i can be ignored.

Therefore the k^{th} inverter module's output power S can be expressed in (1). From (1), when adjusting CHB's output voltage phase angle, both active power and reactive power can be changed accordingly.

$$S=\frac{\sum_{i=1}^{n}V_ie^{j\theta_i}}{Z_X}V_ke^{j\theta_k}=\frac{V_{out}e^{j(\theta_{total}-\theta_X)}}{|Z_X|}V_ke^{j\theta_k} \tag{1}$$

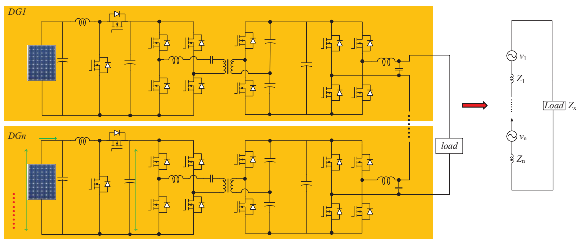

Fig. 1 CHB inverter system on island mode

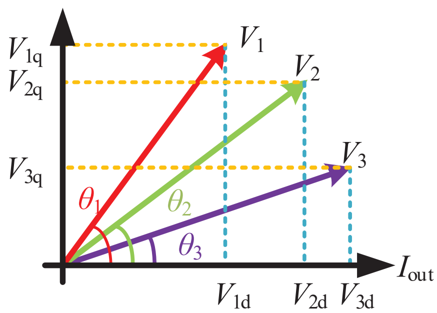

Fig. 2 The Output Voltage when three inverters in series

Suppose there are three inverter modules, the amplitude and phase angle between each inverter and PCC current are expressed as V_1,V_2,V_3 and θ_1, θ_2, θ_3 respectively. Suppose the active power proportions and reactive power proportion within different inverters are k_1, k_2, k_3 and m_1, m_2, m_3 respectively. Then (2),(3) should be satisfied. Moreover, the PCC voltage V_{pcc} can be expressed in (4).

$$k_1V_1\cos(\theta_1)=k_2V_2\cos(\theta_2)=k_3V_3\cos(\theta_3) \tag{2}$$

$$m_1V_1\sin(\theta_1)=m_2V_2\sin(\theta_2)=m_3V_3\sin(\theta_3) \tag{3}$$

$$V_{pcc}=\frac{\sqrt{(\sum_1^3 V_i\cos(\theta_i))+(\sum_1^3 V_i\sin(\theta_i))}}{\sqrt{2}} \tag{4}$$

Instead of utilizing power factor as feedback to adjust frequency (PF-*f*)[17], an improved method that adapts reactive power as feedback to adjust frequency (*Q*-*f*) is expressed in (5), where C_i and Q_i are the i^{th} inverter's droop coefficient and reactive power respectively. Furthermore, in order to keep reactive power proportions within different inverters, then C_1, C_2, C_3 should be inverse to m_1, m_2, m_3 respectively and it is expressed in (6).

$$\omega_i=\omega_{ref}+C_iQ_i \tag{5}$$

$$\frac{m_1}{C_1}=\frac{m_2}{C_2}=\frac{m_3}{C_3} \tag{6}$$

Based on (5) and (6), Then (4) can be re-expressed in (7).Since k_1, k_2, k_3 and m_1, m_2, m_3 are the known parameters, the amplitude of the q^{th} module can be calculated according to the phase angle between its output current and output voltage. It is noticeable that each inverter can calculate its own output voltage based on (5) and (7), and there is no need to get the information from other inverter. So, the communication within different converters are avoided and the cost of the whole system is decreased.

$$V_q=\frac{2V_{pcc}^2}{\left(\cos(\theta_q)\sum_{i=1}^{i=3}\left(\frac{k_i}{k_q}\right)\right)^2+\left(\sin(\theta_q)\sum_{i=1}^{i=3}\left(\frac{m_i}{m_q}\right)\right)^2} \tag{7}$$

$$q\in(1,2,3)$$

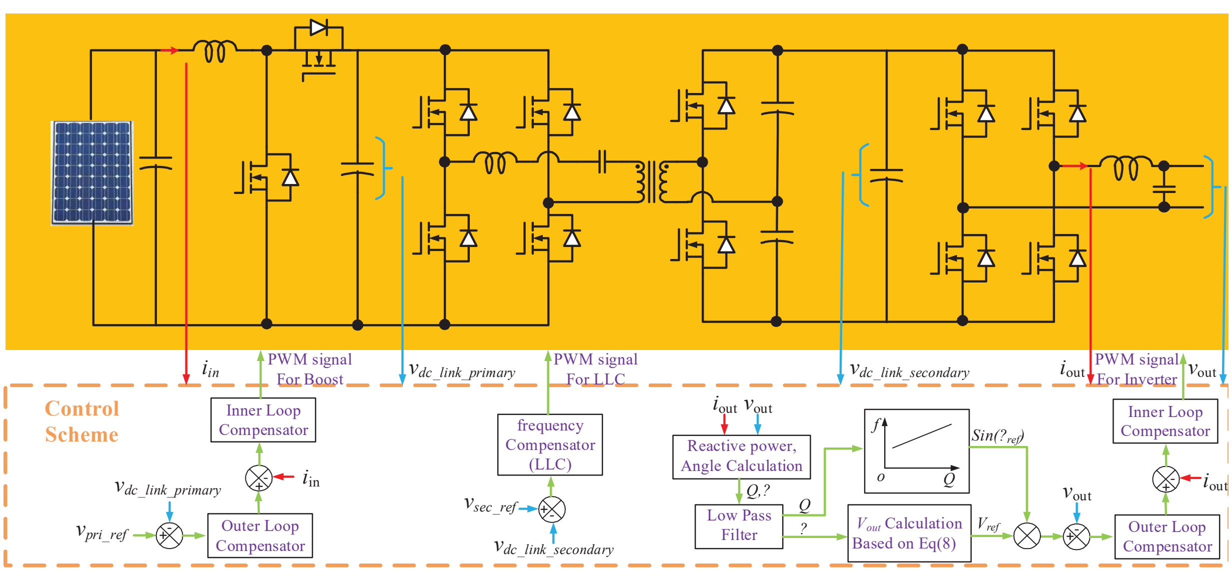

Fig. 3 Control Scheme of every CHB block

B. Power Proportional Distribution Range

Based on (2) and (3), each inverter's phase angle and amplitude are expressed in (8) and (9) respectively.

$$\varphi_n = \tan^{-1}\left(\frac{k_n}{m_n}\tan\theta_{load}\right) \quad n \in \{1,2,3\} \tag{8}$$

$$V_n = V_{pcc}\sqrt{(k_n cos(\theta_{load}))^2 + (m_n sin(\theta_{load}))^2} \tag{9}$$

Suppose each inverter's DC side voltage is V_{dc}, then (10) and (11) should be satisfied.

$$V_n \leq V_{dc} \tag{10}$$

$$\left|\sum_{K\neq n} \vec{V_k}\right| \leq (N-1)V_{dc} \quad N=3 \tag{11}$$

According to derivation from (10) and (11), the allowed range of power portion distribution when V_{dc} is 40V and V_{pcc} is 70.7V is located inside the red-dashed rectangle in Fig. 4. P and Q represents the power portion distribution of active and reactive power respectively.

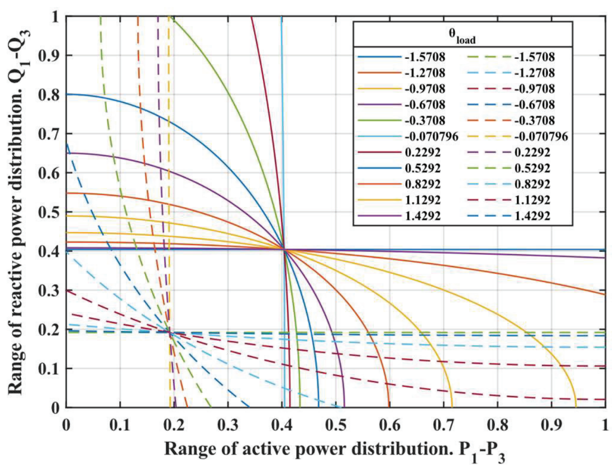

Fig. 4 The power proportion of P and Q when V_{dc} is 40V & V_{pcc} is 70.7V

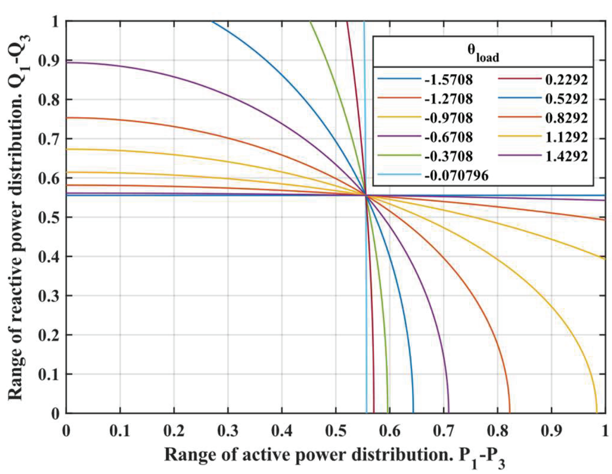

Fig. 5 The power proportion of P and Q when Vdc is 55V & Vgrid is 70.7V

The allowed range of power portion distribution when V_{dc} is 55V and V_{pcc} is 70.7V is located inside the red-dashed rectangle in Fig. 5. When the DC side voltage increases from 40V to 55V, the wider power proportion range will be derived, and the load value doesn't make any influence on the range of power proportion distribution.

III. CONTROL STRATEGY

Each distribute inverter module's control scheme is shown as Fig. 3. The boost stage adapts primary side voltage as outer loop feedback variable and inductor current as inner loop feedback variable. The LLC circuit feedbacks secondary side voltage to adjust the PWM frequency.

For inverter stage, according to control algorithm mentioned in previous section, the reactive power is calculated according to each inverter's output voltage and output current. In order to calculate the phase angle within PCC current and each inverter's output voltage, the classic digital PLL calculation method is adopted [20]. Since the calculated reactive power contains harmonic component, so the digital low pass filter is adopted to get the DC component. The -3dB turning frequency of low pass filter is set as 100Hz. Then each inverter's angular velocity can be calculated according to (5). The parameter C_i directly influence the dynamic response of the system. And each inverter's output voltage is calculated according to (7). It is noticeable that the active power is not adopted as feedback variable, so the active power portion distribution's precision is not as good as reactive power. Based on above calculation result, output voltage reference can be derived. Then PR control method is adopted to control the output voltage. Inner current loop is adopted since it can reduce the resonant peak that LC filter contains. The inverter's inductor value is 15μH and output capacitor is 10μF. The detailed parameter is shown as TABLE I and the transfer function is expressed in (12) where k_{il} is the inner loop portion coefficient.

$$G_O = \frac{k_{iL}V_{dc}}{s^2LC + sC(R_L + k_{iL}V_{dc} + \frac{L}{CR_{load}}) + \frac{R_{load} + k_{iL}V_{dc} + R_L}{R_{load}}} \tag{12}$$

Fig. 6 Bode diagram that v_q* to v_q

The bode diagram that v_q* to v_q is shown as Fig. 6. By adding inner inductor current loop, the resonant peak is eliminated and the robustness is improved. In order to improve