# Reverse Droop Control of Distributed Generation Inverters in Low Voltage Microgrid

**Dr. Chethan Raj D**
School of Electrical and Electronics Engineering
BMSE, Bengaluru, INDIA
chethanraj9@gmail.com

**Dr. Vivekanandan Subburaj**
School of Electrical and Electronics Engineering
REVA University, Bengaluru, INDIA
vivekanandan.subburaj@reva.edu.i

**Dr. Santoshkumar Hampannavar**
School of Electrical and Electronics Engineering
REVA University, Bengaluru, INDIA
vivekanandan.subburaj@reva.edu.in

**Abstract:** In the low-voltage microgrid system with multi-inverter running in parallel, due to the impedance difference of each inverter output line, it is difficult for the distributed power generation units in the system to allocate the active power of the public load according to the traditional anti-droop control strategy, which affects the stability of the system. In view of this problem, the output power distribution performance of low voltage microgrid system is analyzed theoretically, and the main factors affecting the power distribution performance are obtained. The introduction of virtual resistance into the double-closed-loop control of voltage current not only inhibits the effect of coupling between active and reactive power on the stability of the system, but also improves the output power quality of the system. Virtual resistance can track the change of active power difference between active power and reference output of each distributed power supply in real time and compensate for the bus voltage drop due to line impedance difference in time and effectively. The proposed strategy enables each distributed power supply to distribute the active power in the public load reasonably. Finally, the validity and correctness of the strategy are verified on the simulation platform.

**Keywords**

## 1. INTRODUCTION

With the emergence of the non-renewable energy crisis and the enhancement of the greenhouse gas effect, various new energy sources such as wind, solar and tidal energy have become the focus of more and more researchers. At present, the utilization of new energy in the power system is mainly distributed power supply system with microgrid as the carrier. The microgrid system consists of distributed power sources (Distributed Generator, DG), loads and controllers, etc., to provide users with electrical energy [1]. In recent years, the power distribution performance of microgrids has attracted the attention of domestic and foreign scholars [2-5].

In the microgrid system, when the peer-to-peer control mode is used to control each DG in the system, the dependence of each DG on the communication equipment is greatly reduced, and the control only depends on the local information of the system [6]. In this control mode, the selection of each DG control strategy in the microgrid system is very important, which has caused Droop control to be widely used [7].

Droop control is a common control method for parallel operation of multiple DGs in microgrid systems. It not only provides voltage and frequency support for the system, but also realizes reasonable power distribution according to their respective droop characteristic equations [8]. However, the droop control also has the following problems: (1) Due to the inherent characteristics of the microgrid system, it is difficult for the traditional droop control strategy to give full play to the energy supply efficiency of the DGs in the system, and even affect the stability of the system [9-11]; (2) The selection of the droop control method is related to the voltage level of the microgrid system. The low-voltage microgrid system uses traditional anti-sag control.Similar to traditional droop control, it also has the advantages of small fluctuations and plug and play [12-14].

In order to solve the problem that the power distribution accuracy of the microgrid system is reduced due to the traditional anti-sag control, domestic and foreign scholars have proposed a variety of improvement strategies. Literature [15-17] introduced virtual impedances on the basis of traditional anti-sag control strategies to mitigate the adverse effects of power coupling between inverters on the microgrid system, but they did not consider the impact of virtual impedance on the bus voltage Influence. Literature [18-20] used methods such as constructing adaptive virtual resistance or adaptive virtual impedance to compensate for the voltage drop generated by virtual impedance or virtual resistance while suppressing the system's circulating current.However, the above-mentioned adaptive virtual control strategy increases the line voltage drop and cannot take into account the power quality.

Literature [21-23] respectively proposed an adaptive droop coefficient to achieve the purpose of power sharing, but the adjustment of the adaptive droop coefficient is still poorly adjusted, resulting in poor dynamic performance. Although the above-mentioned improved droop control strategy improves the power distribution accuracy of the system to varying degrees, there is no experiment to prove the improvement effect of the power quality of the system. Aiming at the characteristics of R-X in low-voltage micro-grid systems, this paper proposes a low-voltage micro-grid power distribution strategy based on adaptive virtual impedance based on the P-V relationship [24].This method can improve the distribution accuracy of the output power of each DG in the microgrid system when the impedance of each DG output line is resistive.

Finally, simulation experiments verify the feasibility of the strategy proposed in this paper.

## 2. POWER FLOW CHARACTERISTICS BETWEEN DISTRIBUTED GENERATION INVERTERS

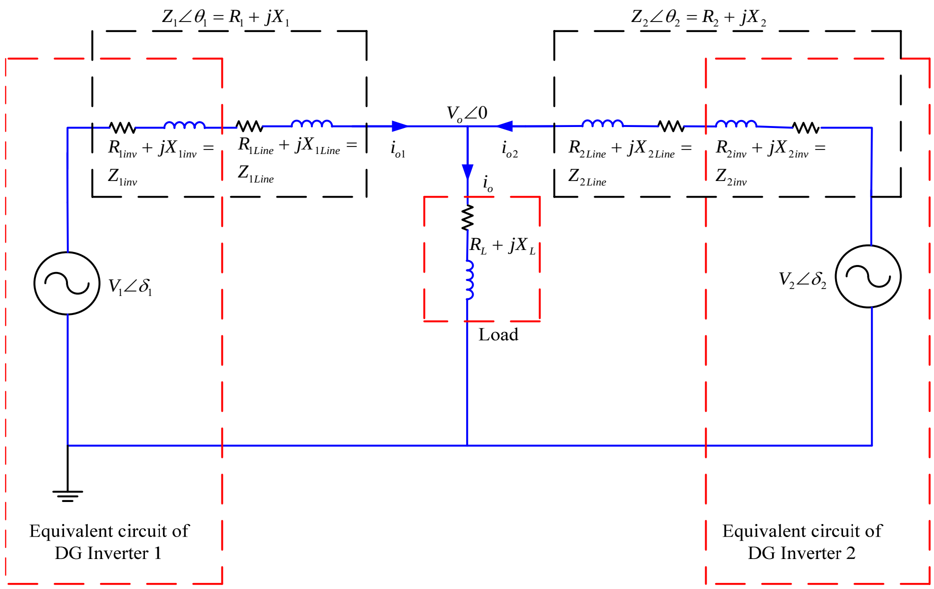


**Figure 2.1** Equivalent circuit diagram of DG inverter parallel operation

The voltage source distributed generation inverter is an important way to connect the distributed power supply and the power grid in the microgrid. The regulation characteristics of the DG inverter are crucial for the power distribution between the distributed generation sources. The DG inverter with droop control can adjust its own frequency and power according to measured active and reactive power.

The following is an overview of the basics of droop control using Figure 1 to analyses the output power of two DG inverters operating in parallel. The sum of the line and output impedance of the DG inverter1 and DG inverter 2 is given by [3]:

The equivalent circuit impedance $Z_n(n=1,2)$ is:

$$Z_n = R_n + jX_n \tag{1}$$

The DG inverters output current (n=1,2) is:

$$i_n = \frac{V_n\angle\delta_n - V_o\angle 0}{Z_n\angle\theta_n} \tag{2}$$

The output power of DG inverters (n=1,2) is:

$$S_n = P_n + jQ_n = V_n\angle\delta_n . i_n^* \tag{3}$$

$P_n$ is the output active power of DG inverter n; $Q_n$ is the output reactive power of DG inverter n; $i_n^*$ is the output current conjugate.

$$P_n = \frac{1}{Z_n}[(V_nV_o\cos\delta_n - V_o^2)\cos\theta_n + V_nV_o\sin\delta_n\sin\theta_n)] \tag{4}$$

$$Q_n = \frac{1}{Z_n}[(V_nV_o\cos\delta_n - V_o^2)\sin\theta_n - V_nV_o\sin\delta_n\cos\theta_n)] \tag{5}$$

When the impedance of the DG inverter system is resistive $\theta = 0^o$ , the active and reactive power of the DG inverter output respectively is:

$$P_n = \frac{V_o(V_n - V_o)}{R_n} \tag{6}$$

$$Q_n = -\frac{V_n V_o}{R_n}\delta_n \tag{7}$$

Droop control is actually controlled by the principle of linear relationship between the power of the inverter output and the amplitude of the system frequency and output voltage. The Droop control method is generally used in the control of distributed generation units in the Peer-to-peer control strategy [8].

Reverse droop control strategy can be derived [9,10]:

$$V_n - V_{ref} = -m_{PV}(P_n - P_{ref}) \tag{8}$$

$$f_n - f_{ref} = n_{Qf}(Q_n - Q_{ref}) \tag{9}$$

Where $f_{ref}$ is the nominal frequency of the system and $f$ is the actual frequency of the system; $V_{ref}$ is the rated voltage of the system and $V$ is the actual output voltage of the system. $Q_{ref}$ is the system rated reactive power and $Q$ is the actual output reactive power; $m_{PV}$ is the reverse droop(P-V) coefficient and $n_{Qf}$ is the reverse(Q-f) droop coefficient. Figure 2 shows the droop characteristics of reverse droop control[Chen (2014), Wang (2014)].

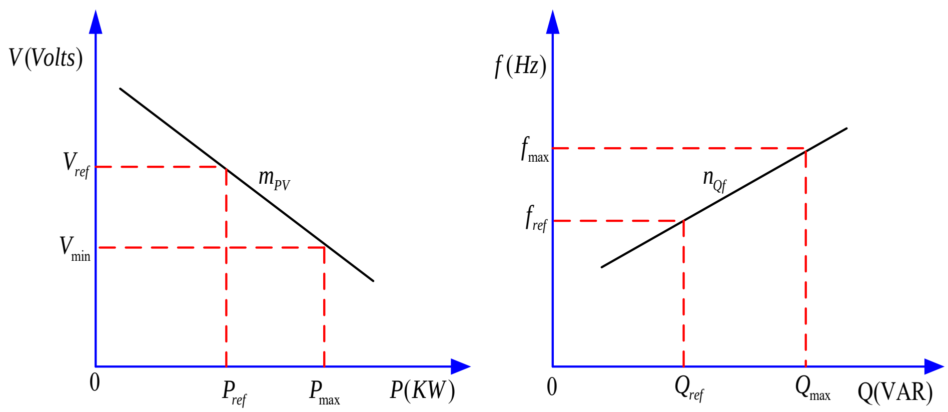


**Figure 2.2** Reverse droop control curves

## 3. DIAGRAM OF REVERSE DROOP CONTROL

In a microgrid, a reverse droop control is used to adjust the voltage and frequency of the DG inverters output, so that the micro-grid can operate under different load requirements. As can be seen from Figure 3, where $L_f$ is the filter inductor, $C_f$ is the filter capacitor, $r$ is the filter inductor equivalent resistance and $Z_{Load}$ is the load impedance, the reverse droop control model of microgrid can be divided into two parts: voltage and current loop control model and power droop control model. First, the output voltage and current of the microgrid power supply are obtained by sampling the DG inverter module. The output power of the microgrid power supply is obtained by the power calculation unit and the low-pass filter and then calculated according to the active power droop controller and the reactive power droop controller respectively. The reference voltage values $V_{dref}$ and $V_{qref}$ is finally adjusted by the voltage PI control and $i_{dref}$ and $i_{qref}$ are adjusted by the current P control to obtain controllable sinusoidal modulation signal $m$ to the DG inverter[10,11] .

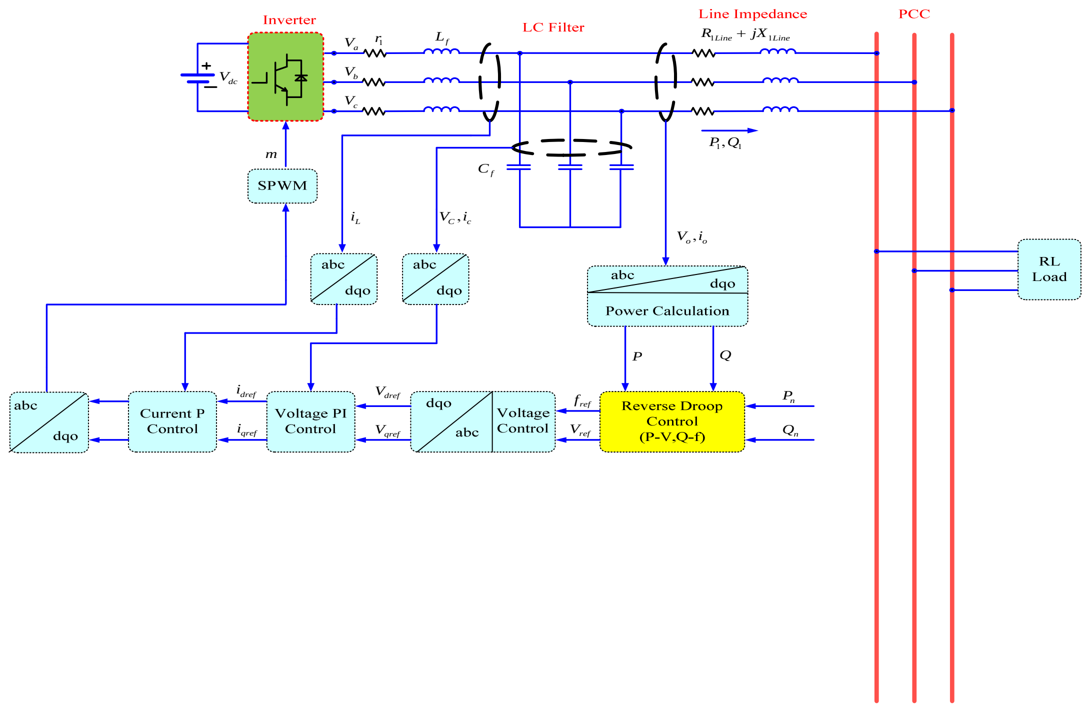


**Figure 3.1** Control diagram of reverse droop control

From the above analysis, it can be seen that the output impedance of the inverter is complex and its nature is uncertain. In general, the output impedance of the inverter itself is small and the output impedance characteristic is determined by the line impedance. However, the impedance of the line at the output end of the inverter in the microgrid is flexible and it is not possible to use the reverse droop control directly [12-13].

### 3.1 Vitrual Resistance Method:

Decoupling the output power requires knowing exactly the information of the output impedance and requires real-time on-line impedance measurement. This technology is still under research and is not mature enough. Therefore, the output impedance of the DG inverter is altered using virtual resistance method as shown in the figure 4[14-15]:

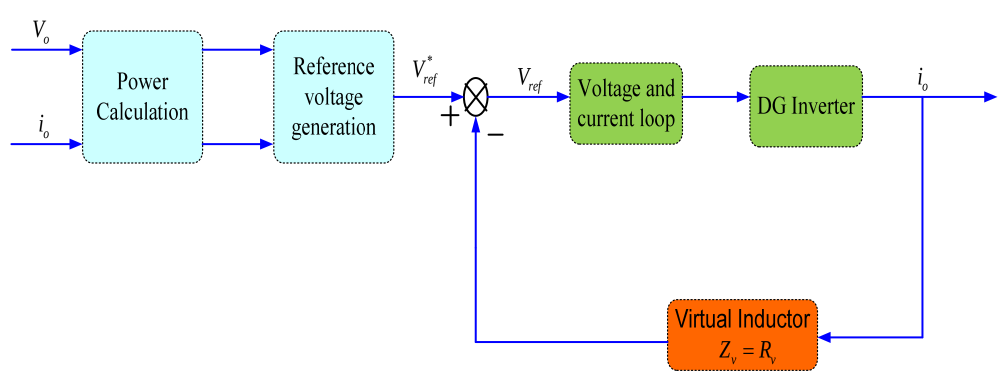


**Figure 3.2** Virtual resistance block diagram.

When the load is suddenly changed, the voltage amplitude and frequency are adjusted to obtain a good power sharing effect. This method can achieve accurate power sharing, has better dynamic modification performance and is suitable for resistive line impedance conditions[15-16].

Virtual resistor is expressed as:

$$Z_{vir}(s) = R_v, Z_o(s) = \frac{C_1 s^2 + C_2 s + C_3}{C_4 s^3 + C_5 s^2 + C_6 s + C_7} \tag{10}$$

$$\begin{aligned} &C_1 = L, C_2 = r + K_{pi} K_{pwm} K_{pv} R_v, C_3 = R_v K_{pi} K_{pwm} K_{vi}, C_4 = LC \\ &C_5 = rC + K_{pi} K_{pwm} C, C_6 = 1 + K_{pi} K_{pwm} K_{vi}, C_7 = K_{pi} K_{pwm} K_{vi} \end{aligned} \tag{11}$$

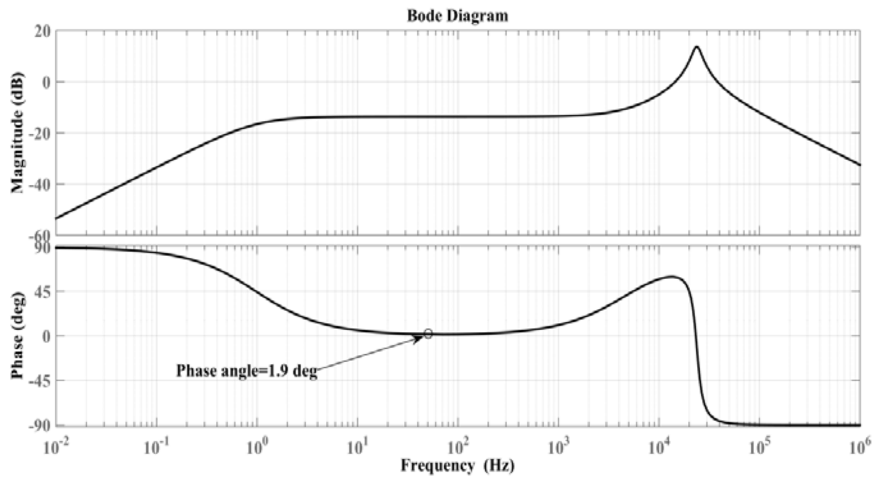


**Figure 3.3** Bode diagram of inverter output impedance with virtual resistor.

If the line impedance is resistive, virtual resistor is added the control loop of reverse (*P-V/Q-f*) droop control to improve the power decoupling effect. Impedance angle at 50 Hz is $1.9^\circ$ as shown in the Figure 5. The parallel inverter output impedance tends to be more resistive, which has a major role in improving the power sharing.

## 4. SIMULATION RESULTS

Power sharing analysis of reverse droop control with virtual resistors under resisive line impedance with frequent changes in load.

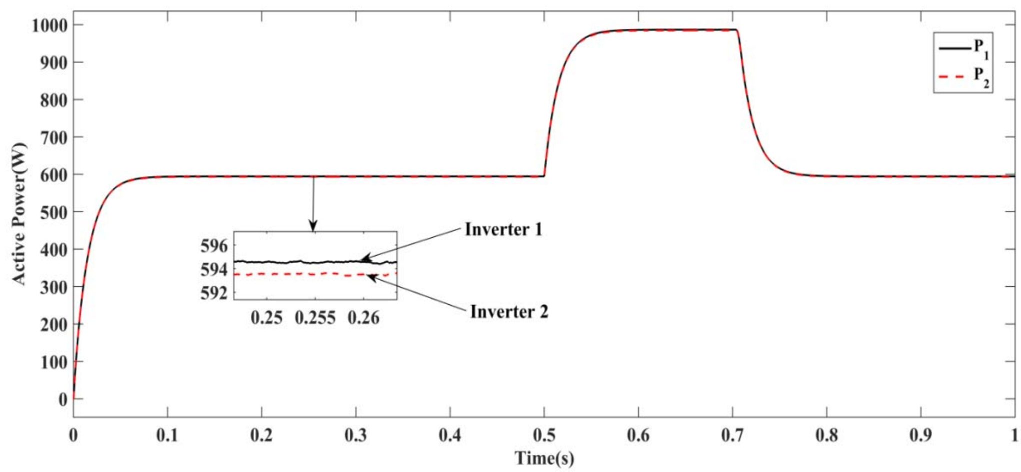


**Figure 4.1** Active power sharing using reverse droop control with virtual resistors under resistive line impedance with frequent changes in load.

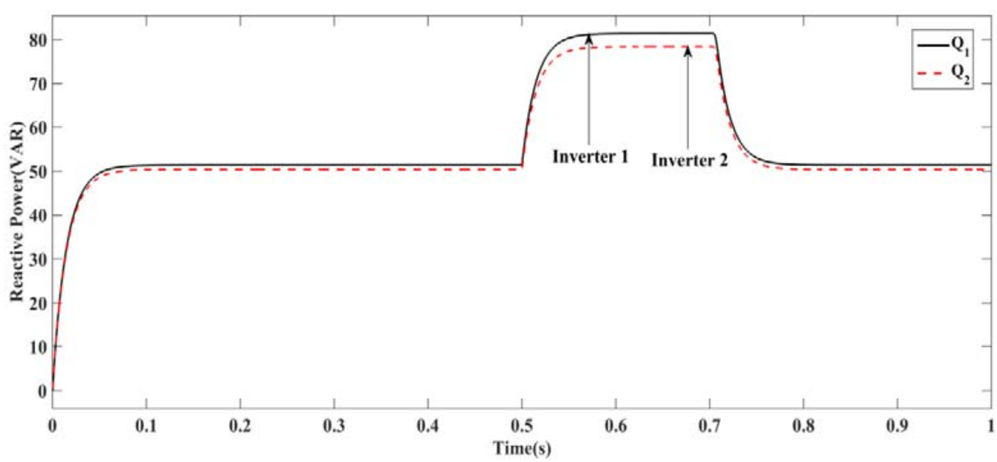


**Figure 4.2** Reactive power sharing using reverse droop control with virtual resistors under resistive line impedance with frequent changes in load.

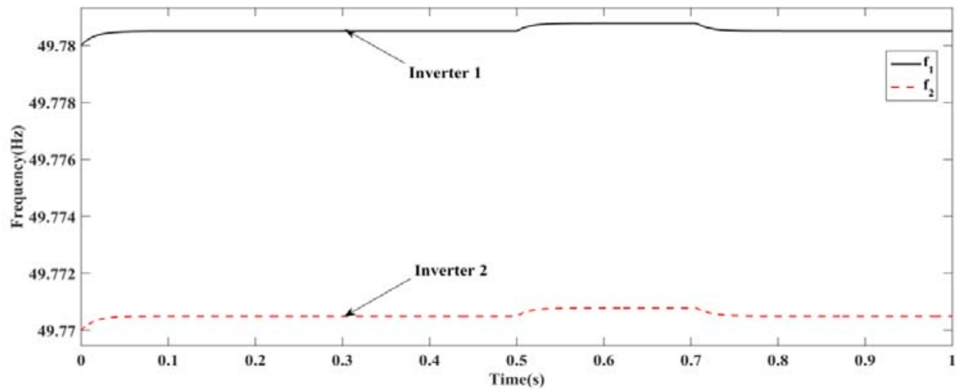


**Figure 4.3** Parallel DG inverters output frequency using reverse droop control with virtual resistors under resistive line impedance with frequent changes in load.

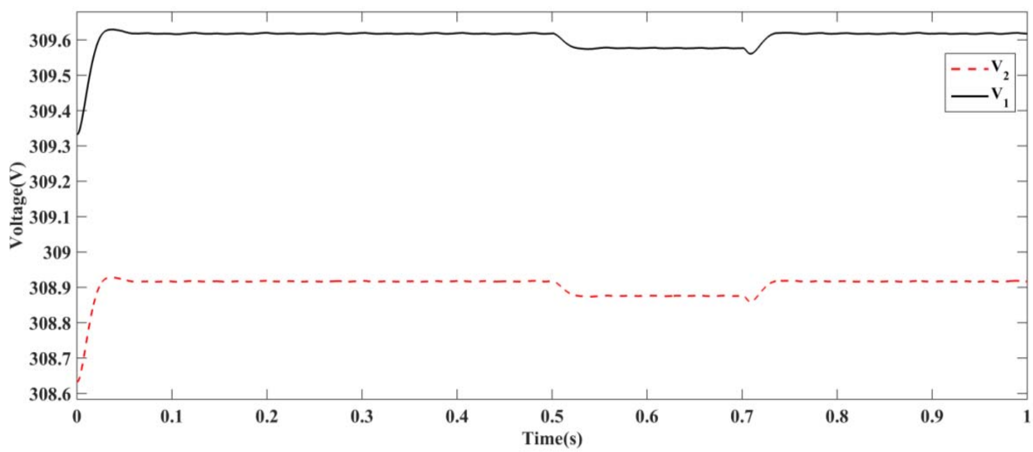


**Figure 4.4** Parallel DG inverters output voltage amplitude using reverse droop control with virtual resistors under resistive line impedance with frequent changes in load.

Power sharing of parallel inverters is investigated with common load of $P_{load}$ = 1201 W, $Q_{load}$ = 121 VAR and at 0.5 s sudden local load value of $P_{load}$ = 801 W, $Q_{load}$ = 81 VAR is added and removed at 0.7s verify the dynamic response and line impedance of $R_{1Line} + jX_{1Line}$ =0.7+j0.002Ω, $R_{2Line} + jX_{2Line}$ =0.8+j0.003Ω. Reverse droop control based on virtual resistors can reduce the influence of the line impedance difference on the parallel inverters by setting the total output impedance of the DG inverters to be resistive, which improves decoupling of power and improves the proportional load sharing $P_1$=594 W, $P_2$=592 W, $Q_1$=53 VAR, $Q_2$=52 VAR and at load change at 0.5 s, $P_1$=935 W, $P_2$=932 W, $Q_1$=89 VAR, $Q_2$=86 VAR as shown in the Figure 6,7 and frequency variation of DG inverters is within the range of 49.77 Hz to 49.78 Hz, the maximum fluctuation of 0.004 Hz as shown in the Figure 4.32. Voltage variation of DG inverters is $V_1$=309.6 V, $V_2$=308.9 V as shown in the Figure 8,9. Thus, the reverse droop control with virtual resistors improves power sharing compared to reverse droop control.

## 5. CONCLUSION

This paper proposes an improved traditional reverse droop control strategy suitable for virtual resistance in low-voltage microgrid systems. Under the premise that the output impedance of the inverter is made resistive through design parameters in the literature, adaptive virtual resistance is introduced. The virtual resistance value varies with the difference between the actual output active power of the DG and the reference output active power. The design of the virtual resistance link aims to eliminate the adverse effect of the excessive voltage drop of each DG in the system caused by the introduction of the virtual resistance link and achieve the purpose of evenly distributing the output active power of each DG to the public load.

## 6. REFERENCES


[1] LASSETER B. Microgrids distributed power generation[C] // 2001 IEEE Power Engineering Society Winter Meeting, 2001, 1: 146-149.

[2] FANG Lei, NIU Yugang, WANG Siming, et al. Optimal capacity determination method based on day-ahead scheduling and real-time control[J]. Power System Protection and Control, 2018, 46(23): 102-110.

[3] WANG Chunmei, XIONG Binyu. Two-stage method for unbalanced power smoothing in microgrid based on energy storage dispatch mode[J]. Smart Power, 2019, 47(2): 22-29.

[4] ROCABERT J. Control of power converters in AC microgrids[J]. IEEE Transactions on Power Electronics, 2012, 27(11): 4734-4749.

[5] VANDOOM T L, KOONING J D, MEERSMAN B, et al.Automatic power sharing modification of P/V droop controllers in low voltage resistive microgrid[J]. IEEE Transactions on Power Delivery, 2012, 27(4): 2318-2325.

[6]GUO Wenming, MU Longhua. Control principles ofmicro-source inventers used in microgrid[J]. Protection and Control of Modern Power Systems, 2016, 1(1).

[7] WANG Chengshan, XIAO Chaoxia, WANG Shouxiang. Integrated control and analysis of micro-power grid[J]. Automation of Electric Power Systems, 2008, 32(7): 98-103.

[8] GUO Qian, LIN Liaoyuan, WU Hongyan, et al. Distributed power control strategy for microgrids considering adaptive virtual impedance[J]. Automation of Electric Power Systems, 2016, 40(19): 23-29.

[9]LI Y W, KAO C N. An accurate power control strategy for inverter based distributed generation units operating in a low voltage microgrid[J]. IEEE Transactions on Power Electronics, 2009, 24(12): 2977-2988.

[10] LOPES J A P, MOREIR C L, MADUREIARA A C.Defining control strategy for microgrids islanded operation[J]. IEEE Transactions on Power Systems, 2006, 21(2): 916-924.

[11] IYER S V, BELUR M N, CHANDORKAR M C. Analysis and mitigation of voltage offsets in multi-inverter microgrids[J]. IEEE Transactions on Energy conversion, 2011, 26(1): 254-63.

[12] LAAKSONEN H, KOMULAINEN R. Voltage and frequency in inverters based weak LV network microgrid[C] // 2005 International Conference on Future Power Systems, November 18-18, 2005, Amsterdam, Netherlands.

[13] Research on control strategy of low-voltage microgrid parallel inverter[J]. Smart Power, 2019, 46(7): 34-39.

[14] WANG Chengshan, XIAO Chaoxia, WANG Shouxiang. Multiple feedback loop control scheme for inverters of the micro-source in microgrids[J]. Transactions of China Electrotechnical Society, 2009, 24(2): 100-107.

[15] YUAN Chang, CONG Shixue, XU Yanhui. Overview on grid-connected inverter virtual impedance technology for microgrid[J]. Power System Protection and Control, 2017, 45(9): 144-154.

[16] ZHAO Qiao'e, ZHANG Lele, WU Xiaodong, et al. Control strategy for multi-inverters based on parallel virtual resistance[J]. Power System Protection and Control, 2017, 45(15): 30-39.

[17] HE Jinwei. An islanding microgrid power sharing approach using enhanced virtual impedance control scheme[J]. IEEE Transactions on Power Electronics, 2013, 28(11): 5272-5282.

[18] KANG Yingwei, WANG Duhong, ZHANG Jingwei, et al. Droop control strategy for multi-resistive inverters of low voltage microgrid based on adaptive virtual impedance[J]. Science Technology and Engineering, 2017, 17(10):40-45.
[19] MAHMOOD H. Accurate reactive power sharing in an islanded microgrid using adaptive virtual impedances[J].IEEE Transactions on Power Electronics, 2015, 30(3): 1605-1617.
[20] ZHANG Huaguang. Distributed adaptive virtual impedance control for accurate reactive power sharing based on consensus control in microgrids[J]. IEEE Transactions on Smart Grid, 2017, 8(4): 1749-1761.
[21] XU Jiqiang, LU Wenzhou, WU Lei. Self-regulation sag coefficient control strategy for low voltage microgrid inverter[J]. Motor and Control Application, 2017, 44(6): 13-18.
[22] SUN Xiaofeng, YANG Yalin, ZHAO Wei, et al. Adaptive droop control strategy for microgrid inverter[J]. Power System Technology, 2014, 38(9): 2386-2391.
[23] GUO Tong, LI Yanqing, TONG Nian, et al. Control strategy of microgrid based on self-adjusting droop coefficient[J]. Journal of Electric Power Science and Technology, 2017, 32(2): 77-83.
[24] LAAKSONEN H, SAARI P, KOMULAINEN R. Voltage and frequency control of inverter based weak LV network microgrid[C] // 2005 International Conference on Future Power Systems, November 18-18, 2005, Amsterdam, Netherlands.
[25] YAO W, CHEN M, MATAS J, et al. Design and analysis of the droop control method for parallel inverters considering the impact of the complex impedance on the power sharing[J]. IEEE Transactions on Industrial Electronics, 2011, 58(2): 576-588.
[26] LAAKSONEN H, SAARI P, KOMULAINEN R. Control of voltage and frequency in inverter and synchronous generator based urban LV microgrid[C] // Proceedings the Sixth IASTED International Conference on European Power and Energy Systems, 2006: 26-28.