# Virtual Impedance-Based Power Control Strategy with Variable Resistance-Inductance Ratio for Low-Voltage Microgrids (Postprint)

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## Abstract

In low-voltage microgrids, traditional droop control exhibits coupling, and line impedance mismatch makes it difficult for inverters to precisely control their output power, readily causing circulating currents among inverters. This paper analyzes the output power characteristics of inverters, derives the coupling relationship between the line resistance-inductance ratio and droop control through the introduction of virtual power, and proposes a power decoupling control strategy based on virtual impedance. By adding a virtual impedance control loop, the strategy modifies the equivalent resistance-inductance ratio of the inverter output to achieve decoupling of power control, while simultaneously addressing the problem of unequal power sharing among inverters during both normal operation and load variations. A simulation model of the fundamental low-voltage microgrid structure is constructed using Matlab/Simulink, and validation through comparison with traditional droop control demonstrates the effectiveness of the proposed strategy.

## Full Text

## Preamble

### Research on Power Control Strategy for Low-Voltage Microgrids with Variable Impedance Ratio Based on Virtual Impedance

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## Abstract

In low-voltage microgrids, traditional droop control suffers from coupling effects, and mismatched line impedances make it difficult for inverters to precisely control output power, which can cause circulating currents between inverters. This paper analyzes the output power characteristics of inverters and derives the coupling relationship between line resistance-to-reactance ratio and droop control by introducing virtual power. A power decoupling control strategy based on virtual impedance is proposed. By adding a virtual impedance control loop, the strategy modifies the equivalent resistance-to-reactance ratio of the inverter output, achieving decoupled power control while simultaneously solving the problem of unequal power sharing among inverters during normal operation and load variations. A simulation model of the basic low-voltage microgrid structure was built using Matlab/Simulink, and the effectiveness of the proposed strategy was verified through comparison with traditional droop control.

**Keywords:** low-voltage microgrid, virtual impedance ratio, power decoupling, power sharing

## 1 Introduction

Microgrids differ from traditional power grid supply methods. In the microgrid structure shown in [Figure 1: see original paper], distributed generation (DG) units supply power to loads through inverters, which are the core components of DG systems [1-4]. When a microgrid disconnects from the main grid, the DG units must supply all load power within the network. In this scenario, how to equally share power among DG units becomes a critical issue in microgrid operation and control [5].

Currently, voltage and frequency-based droop control is an effective method for achieving power sharing [6-7]. Droop control primarily simulates the primary voltage and frequency regulation characteristics of synchronous generators in traditional power grids, adjusting voltage and frequency through active and reactive power control [8]. However, coupling in droop control reduces power control accuracy and can trigger circulating currents between inverters or inverter overcurrent problems [9-10]. Reference [11] proposed a distributed control approach that coordinates all DG units uniformly and outperforms traditional centralized DG control, but it requires information from all DG units within the microgrid, demanding high communication and information processing capabilities. Reference [12] presented a method using an integral link for the difference between reference and actual power to improve power sharing accuracy, but this also requires interconnection communication and does not address coupling issues. Reference [13] proposed a strategy using repetitive droop control in each sampling period to achieve power sharing. To address droop control coupling, references [14-15] introduced virtual impedance but did not consider compensating for voltage loss caused by virtual impedance, which can lead to voltage instability when the system operates in islanded mode.

This paper proposes a power control strategy for low-voltage microgrids based on virtual impedance with variable resistance-to-reactance ratio. Starting from inverter output power characteristics, the strategy analyzes the relationship between line resistance-to-reactance ratio and power coupling. By introducing a virtual impedance loop into traditional droop control, it uniformly modifies the inverter output resistance-to-reactance ratio to achieve power decoupling and sharing while retaining the advantage of droop control without requiring interconnection communication. Additionally, analysis shows that adding a voltage compensation link in the virtual impedance parameter design can reduce the impact of virtual impedance and load variations on bus voltage.

## 2 Analysis of Inverter Output Power Characteristics in Microgrids

[Figure 2: see original paper] shows the equivalent model of inverter power transmission. Assuming the voltage at the point of common coupling (PCC) is $E\angle 0$, the line impedance is $Z\angle\theta$, and the DG unit is represented by a simplified AC source $V\angle\delta$, where $\delta$ is the phase difference between $E$ and $V$.

The apparent power delivered from the DG to the PCC is expressed as:

$$S = VI^* = V \cdot \frac{V - Ee^{j\delta}}{Ze^{j\theta}}$$

where the superscript "*" denotes the complex conjugate.

Substituting Euler' s formula ($e^{j\theta} = \cos\theta + j\sin\theta$) into equation (1) yields the relationship between active power $P$ and reactive power $Q$ transmitted through the line impedance [9]:

$$P = \frac{V^2\cos\theta - VE\cos(\delta+\theta)}{Z}$$

$$Q = \frac{V^2\sin\theta - VE\sin(\delta+\theta)}{Z}$$

Equation (2) shows that active and reactive power control has a coupling relationship with the line impedance angle, affecting power control accuracy. For low-voltage microgrids with resistive lines, the resistive droop control equations can be expressed as [5]:

$$f - f^* = -k_m(Q - Q^*)$$

$$V - V^* = -k_n(P - P^*)$$

where $f^*$ is the microgrid rated frequency, $P^*$ is the active power output of the DG at rated frequency $f^*$, $V^*$ is the DG output voltage magnitude, $Q^*$ is the reactive power output, and $k_m$ and $k_n$ are the droop coefficients for reactive and active power, respectively. Resistive droop control uses the condition $X \ll R$ as its decoupling basis. When this condition is satisfied, resistive droop control equations can properly distribute power.

## 3 Power Decoupling Control Strategy Based on Virtual Impedance

Virtual impedance is a common method to improve power distribution accuracy [16-17]. By introducing virtual impedance, the influence of line impedance on coupling can be reduced, improving microgrid inverter power distribution accuracy while ensuring stability.

### 3.1 Coupling Analysis of Droop Control

To specifically analyze the coupling relationship in resistive droop control, a linear orthogonal rotation matrix $T$ is introduced to transform the inverter output active power $P$ and reactive power $Q$ into virtual active power $P'$ and virtual reactive power $Q'$:

$$\begin{bmatrix} P' \\ Q' \end{bmatrix} = T \begin{bmatrix} P \\ Q \end{bmatrix}$$

where the linear orthogonal matrix $T$ is:

$$T = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix}$$

### 3.2 Virtual Impedance Implementation

To achieve precise power decoupling, this scheme adds virtual impedance to the inverter's voltage outer loop, making the inverter output resistance-to-reactance ratio $R/X$ large to eliminate the influence of line reactance and impedance mismatch, thereby improving active and reactive power decoupling accuracy and achieving power sharing. Additionally, virtual resistance increases system damping to suppress oscillations and enables indirect control of system line impedance.

After introducing virtual impedance, the voltage outer loop reference voltage is expressed as:

$$\mathbf{v}_{vir} = \mathbf{v}_o^* - Z_{vir}\mathbf{i}_{oabc}$$

where $Z_{vir} = R_{vir} + j\omega L_{vir}$, $\mathbf{v}_o^*$ is the output voltage reference obtained from the droop equations, $\mathbf{v}_{vir}$ is the input reference for the voltage closed loop after combining with the virtual impedance loop, $Z_{vir}$ is the virtual impedance, and $\mathbf{i}_{oabc}$ is the inverter output current.

In the $dq$ rotating coordinate system, the virtual impedance control loop is expressed as:

$$v_{vird} = v_{od}^* - R_{vir} i_{od} + \omega L_{vir} i_{oq}$$

$$v_{virq} = v_{oq}^* - R_{vir} i_{oq} - \omega L_{vir} i_{od}$$

where $R_{vir}$ and $L_{vir}$ are the virtual resistance and virtual inductance, respectively; $v_{vird}$ and $v_{virq}$ are the voltage references for the voltage outer loop in the $dq$ coordinate system; and $\omega$ is the rotation angular frequency of the $dq$ coordinate system. The virtual impedance control loop implementation in the $dq$ rotating coordinate system is shown in [Figure 3: see original paper].

In [Figure 3: see original paper], $v_{od}$ and $v_{oq}$ are the $dq$-axis components of the output voltage feedback values, $i_{ld}^*$ and $i_{lq}^*$ are the $dq$-axis reference values for the current loop, and $k_{pv}$ and $k_{iv}$ are the proportional and integral coefficients of the voltage loop, respectively. The design of voltage and current loops in droop control can be found in reference [13].

In low-voltage microgrids, introducing virtual resistance $R_{vir}$ makes the system impedance $R \gg X$. Therefore, the influence of line reactance $X$ on the system can be neglected, making the system output characteristics resistive. In equation (9), $k_m(P - P^*)$ becomes negligible compared to $rk_m(Q - Q^*)$, and similarly, $k_n(Q - Q^*)$ becomes negligible compared to $rk_n(P - P^*)$, achieving decoupling of inverter output active power $P$ and reactive power $Q$. Uniformly changing the equivalent resistance-to-reactance ratio improves the accuracy of inverter output power.

### 3.3 Virtual Impedance Parameter Design

The equivalent block diagram of the inverter after introducing virtual impedance is shown in [Figure 4: see original paper]. In the figure, $v_{oref}(s)$ is the voltage output by the droop controller, $G_i(s)$ is the current loop transfer function, $G_u(s)$ is the voltage loop transfer function, $u_o(s)$ is the inverter output voltage, $L$ and $C$ are the filter inductance and capacitance of the main circuit, $k_{PWM}$ is the fundamental PWM modulation ratio of the inverter, and $i_o(s)$ is the inverter output current.

The inverter output voltage can be equivalently expressed as:

$$u_o(s) = G(s) v_{vir} - Z_{vir}(s) i_o(s)$$

where $Z_{inv}(s)$ is the inverter equivalent output impedance.

After adding the virtual impedance control loop to the inverter control system, the ratio between resistive and inductive components in the line impedance is changed, but this causes a voltage drop across the virtual impedance, adversely affecting power quality. The system voltage deviation across the inverter, line, and virtual impedance can be derived as:

$$\Delta V = [Z_{inv}(s) + Z_{line}] i_o(s)$$

To improve power quality based on the above analysis of voltage drop causes, the virtual impedance is set as:

$$Z_{vir}(s) = -[Z_0(s) + Z_{line}]$$

In equations (14) and (15), $V_{ref0}$ is the initial given voltage reference of the inverter; $V_{ref}$ is the compensated voltage reference; $E$ is the load-side bus voltage magnitude; and $i_0(s)$ is the load-side bus current. In the virtual impedance control loop, virtual impedance parameters can be calculated according to equation (15).

## 4 Overall Inverter Control Design

The inverter control block diagram based on virtual impedance is shown in [Figure 5: see original paper]. First, based on the line currents $i_{oabc}$ and voltages $v_{oabc}$, instantaneous active power $P$ and reactive power $Q$ are calculated through $dq$ coordinate transformation to obtain currents $i_{odq}$ and voltages $v_{odq}$. According to the droop characteristics of active power vs. frequency and reactive power vs. voltage magnitude, reference voltage magnitude $V'$ and frequency $f'$ are output. After voltage synthesis, $v_{od}^*$ and $v_{oq}^*$ are combined with the instantaneous voltage components of the virtual impedance control loop in the $dq$ axes, $v_{vird}$ and $v_{virq}$, which serve as voltage references for the voltage outer loop. Through voltage and current dual closed-loop control, drive signals are generated to complete the inverter output.

## 5 Simulation Results and Analysis

This paper verifies the improved power decoupling control strategy through simulation in a low-voltage microgrid system. The simulation uses two DG units of equal capacity operating in parallel, building an islanded microgrid model to compare traditional droop control with virtual impedance-based power decoupling droop control. The simulation time is set to 2.5s. Simulation waveforms are shown in [Figure 6: see original paper] and [Figure 7: see original paper], with simulation parameters listed in the table below.

**Table: Simulation System Parameters**

| Parameter | Value |
|---|---|
| System voltage | 380V |
| Line 1 | R = 1.284Ω, L = j0.1930Ω, Length = 0.2km |
| Line 2 | R = 0.812Ω, L = j0.0981Ω, Length = 0.192km |
| Load 1 | 30kW, 10kvar |
| Load 2 | 10kW, 10kvar |
| Load 3 | 10kW, 10kvar |

In low-voltage systems, line impedance is primarily resistive, so P-V droop control is typically employed. [Figure 6: see original paper] and [Figure 7: see original paper] compare the output power of traditional droop control and virtual impedance-based decoupled droop control. In the simulation, only Load1 is connected during 0–0.8s, while Load2 and Load3 are added at 0.8s and 1.6s, respectively. As seen in the results, when traditional P-V droop control is used, the active power deviation between DG1 and DG2 inverters is significant, becoming more pronounced after Load3 is added. However, [Figure 6b: see original paper] shows that reactive power sharing can be achieved.

As shown in [Figure 7: see original paper], after both parallel-operating DG1 and DG2 inverters incorporate the virtual impedance control loop, the overall output power meets the predetermined requirements. During 0.8–1.6s after adding Load2, the total load is 40kW, 20kvar, with both DG1 and DG2 outputting 20kW, 10kvar. At 1.6s when Load3 is added, both DG1 and DG2 output 25kW, 15kvar. During load variations, frequency meets microgrid operation requirements. The results demonstrate that both active and reactive power are precisely shared among inverters.

In [Figure 6c: see original paper], when Load2 is added at t = 0.8s, the system bus voltage drops from 325V to 312V; after Load3 is added at t = 1.6s, the voltage magnitude further drops to 303V. In [Figure 7c: see original paper], when Load2 is added at t = 0.8s, the bus voltage drops from 325V to 316V; after Load3 is added at t = 1.6s, the voltage magnitude initially drops due to the load step but then recovers to 311V. This compensates for the bus voltage drop caused by load increase and virtual impedance introduction, improving the stability of low-voltage microgrid operation.

## 6 Conclusion

To address the coupling issues in traditional resistive droop control and the problem of inverters' inability to precisely control output power, this paper proposes an improved decoupling control strategy based on virtual impedance. Building upon inverter output power characteristics and introducing virtual power, the coupling relationship between line resistance-to-reactance ratio and resistive droop control is derived. When the inductive component cannot be neglected relative to the resistive component, the resulting coupling significantly affects power control accuracy. After introducing the virtual impedance control loop, the inverter output equivalent resistance-to-reactance ratio (R/X) becomes much greater than 1, ultimately achieving precise power decoupling and power sharing among inverters. This approach is suitable for low-voltage microgrid systems with parallel inverters of equal capacity. Furthermore, the voltage compensation link in the virtual impedance parameter design reduces bus voltage drop after load increases, enhancing microgrid operational stability.

# References

[1] Ma Yiwei, Yang Ping, Wang Yuewu, et al. Typical characteristics and key technologies of microgrid[J]. Automation of Electric Power Systems, 2015, 39(8): 168-175.

[2] Chen Meng, Xiao Xiangning. Distributed control strategy for voltage unbalance compensation in islanded microgrid[J]. Transactions of China Electrotechnical Society, 2017, 32(10): 145-153.

[3] Wang Shuya, Su Jianhui, Yang Xiangzheng, et al. A review on the small signal stability of microgrid[J]. Journal of Electrical Engineering, 2016, 11(7): 39-45.

[4] Li Daxing, Qiu Wenxiang, Xia Gefei, et al. Research on distributed generation and microgrid access control system[J]. Electrical Application, 2016, 35(22): 26-30.

[5] 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.

[6] Kan Zhizhong, Zhang Chunjiang, Xue Haifen, et al. A novel droop control of three-phase inverters in wireless parallel operation in microgird[J]. Proceedings of the CSEE, 2011, 31(33): 68-74.

[7] Jin Peng, Ai Xin, Wang Yonggang. Reactive power control strategy of microgird using potential function method[J]. Proceedings of the CSEE, 2012, 32(25): 44-51.

[8] Zhu Yixin, Zhuo Fang, Wang Feng, et al. Virtual impedance optimization method for microgrid reactive power sharing control[J]. Proceedings of the CSEE, 2016, 36(17): 4552-4564.

[9] Cheng Junzhao, Wang Wenxi, Chen Jiangbo. Control method for parallel inverters in microgrid based on power coordinate transformation[J]. Automation of Electric Power Systems, 2017, 41(1): 117-121.

[10] Chen Xiaoqi, Jia Hongjie, Chen Shuoyi, et al. Improved droop control strategy based on line impedance identification for reactive power sharing in microgrid[J]. High Voltage Engineering, 2017, 43(4): 1271-1279.

[11] Shafiee Q, Guerrero J M, Vasquez J C. Distributed secondary control for islanded microgrids—a novel approach[J]. IEEE Transactions on Power Electronics, 2014, 29(2): 1018-1031.

[12] Sun Xiaofeng, Hao Yancong, Zhao Wei, et al. Research of power sharing and voltage restoration without communication for islanded microgrid[J]. Transactions of China Electrotechnical Society, 2016, 31(1): 55-61.

[13] Zhu Yixin, Zhuo Fang, Shi Hongtao. Accurate power sharing strategy for complex microgrid based on droop control method[C]. IEEE ECCE Asia

Downunder, 2013: 344-350.

[14] He J, Li YW, Guerrero JM, et al. An islanding microgrid power sharing approach using enhanced virtual impedance control scheme[J]. IEEE Transactions on Power Electronics, 2013, 28(11): 5272-5285.

[15] Guerrero J M, Matas J, Vicuña L G, et al. Decentralized control for parallel operation of distributed generation inverters using resistive output impedance[J]. IEEE Transactions on Industrial Electronics, 2007, 54(2): 994-1004.

[16] He J, Li YW, Guerrero JM, et al. An islanding microgrid power sharing approach using enhanced virtual impedance control scheme[J]. IEEE Transactions on Power Electronics, 2013, 28(11): 5272-5285.

[17] Matas J, Castilla M, de Vicuna L G, et al. Virtual impedance loop for droop-controlled single-phase parallel inverters using a second-order general-integrator scheme[J]. IEEE Transactions on Power Electronics, 2010, 25(12): 2993-3002.

*Note: Figure translations are in progress. See original paper for figures.*