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Research Article

Voltage and Frequency controller for parallel Inverters in Microgrid using Fuzzy logic

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ABSTRACT

Currently, electrical energy generated from renewable energy sources is being used more and more widely. These energy sources gather and form a microgrid. Microgrid can operate in standalone mode or connected to the grid. When the microgrid operates in standalone mode, it must be controlled to stabilize the frequency and voltage in the microgrid. This article proposes a power control method for inverters in the microgrid, the purpose of the proposed method is to stabilize the frequency and voltage in the microgrid. Besides, the proposed control method also adjusts voltage and frequency to improve power quality in the microgrid. This proposed method is based on fuzzy logic to shift the slope of the droop characteristic curve according to the load. The purpose of the proposed method is to improve the accuracy of power sharing for inverters in microgrids, and it also reduces voltage and frequency deviations in microgrids, it improves power quality in microgrid. The focus of this paper is to improve the voltage quality combined with power sharing between inverters to stabilize the voltage and frequency in microgrid by improving the traditional droop controller, because the droop controller is simple, easy to implement, does not need to use communication network, the disadvantage of the traditional droop controller is the fixed droop coefficient. The proposed controller can adjust the droop coefficient according to the load change based on fuzzy logic inference, the controller is simple, and can be applied to complex microgrids with multiple generators and multiple inverters connected in parallel. The proposed controller is simulated for a islanded microgrid with three parallel connected inverters using Matlab/Simulink software to demonstrate the suitability of the proposed method.

Key words: Droop control, power sharing, voltage control, frequency control, fuzzy logic

INTRODUCTION

Distributed energy sources such as wind energy, solar energy,... they are sent through power converters. There are many different types of microgrid configurations, usually microgrids need an inverter to create AC voltage, the AC voltage at the inverter output is supplied to AC loads or connected to the grid.. Power transmission in microgrid achieves high efficiency when inverters are connected in parallel [1–10]. However, in stand-alone mode, the microgrid must have power sharing between inverters connected in parallel to maintain voltage and frequency stability. At the same time, this power sharing will help avoid balancing currents flowing between inverters [1–10].
Based on the power characteristics of the source, previous studies have established a mathematical model for the droop controller to control the power-sharing between inverters operating in parallel. The droop controller controls active power according to frequency and controls reactive power according to voltage. Relationship between active power and frequency; Reactive power and voltage are expressed through slope coefficients [1–12]. Therefore, researchers relied on the slope factor to realize power sharing between parallel-connected inverters. However, previous studies often fixed these slope coefficients [1–12], so when load parameters change a lot, the resulting voltage and frequency at the output of the inverters given by this droop controller will have a much larger deviation from the rated value.

Several studies have presented traditional droop control methods for power sharing. The purpose of this study is to share power among inverters without aiming to reduce voltage and frequency deviation to improve power quality. However, the traditional droop controller is affected by the line impedance parameter. Therefore, there have been several studies presenting improved droop control methods [10–15] for power sharing. However, the purpose of these studies is to improve the accuracy of power-sharing for inverters without aiming to reduce voltage and frequency deviations to improve power quality.

Therefore, this paper designs a droop controller combined with fuzzy logic to overcome the disadvantages of previous controllers.

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The contributions of the proposed controller are described below:
The droop-fuzzy logic controller automatically adjusts the slope of the droop characteristic curves when the load changes. Therefore, this controller will minimize the frequency and voltage deviation, it improves power quality in microgrid.
In addition, the droop-fuzzy logic controller correctly power-sharing between the parallel-connected inverters in the Microgrid.
Typically, the structure of an islanded microgrid consisting of inverters operating in parallel is shown in Figure 1. In standalone mode, the microgrid must be capable of self-stabilizing voltage and the frequency under load conditions changes in real-time.
Typically, the traditional power control scheme of an independent microgrid includes two control loops:

- The outer control loop is the power control loop. Previous studies often used a droop controller for this control loop, because the droop controller is easy to use, does not require communication, and is easy to change. However, the droop controller will give incorrect power division results in the case of different line impedances, or different inverters. Therefore, in this article, we propose a method to improve the droop controller by using fuzzy logic.
- The internal control loop is a voltage control loop and a current control loop. This control loop will control the voltage and current at the output of the inverter according to the reference voltage and current values.

The block diagram of the proposed controller is shown in Figure 2.

METHOD

Theoretical basis of the proposed control method

The traditional droop controller for dividing power between inverters is established based on the equivalent circuit of the inverter connected to the load through a line as shown in Figure 3.

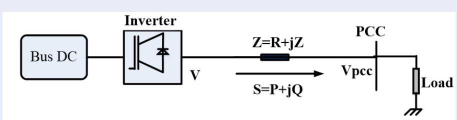

Figure 3: The equivalent circuit of the inverter connects to the load through the line

According to research [1–12], the power running on the line is calculated according to the expression as Eq. 1 (Figure 23):
In there:
R(Ω) and X(Ω) are impedance parameters of the line.
V(voltage) is the voltage at the beginning of the line.
P(W) and Q(Var) are the powers running on the line.
V_{PCC}(voltage) is the voltage at the PCC.
δ is the phase difference angle of the voltage V anh V_{PCC}: $\delta = \delta_1 - \delta_2$

$$\dot{Z} = Ze^{j\theta} = R + jX$$

Transforming expression (1), we have: Eq. (2) and Eq. (3) (Figure 23)
The actual angle between the output voltage of inverters and PCC bus voltage δ is a small value, so $\sin\delta \approx \delta$ and $\cos\delta = 1$, X>>R, from equation (2) and (3) we have: Eq. (4) and Eq. (5) (Figure 23)
Equations (4) show that: P depends on frequency f. From there, we can establish P/f droop controller to control the active power of the inverters as Eq. 6 (Figure 23):
The droop graph of equation (6) is drawn in Figure 4. Figure 4 shows that when the power P changes, the frequency f also changes. If the load increases significantly, the frequency will decrease significantly compared to the rated value and vice versa.

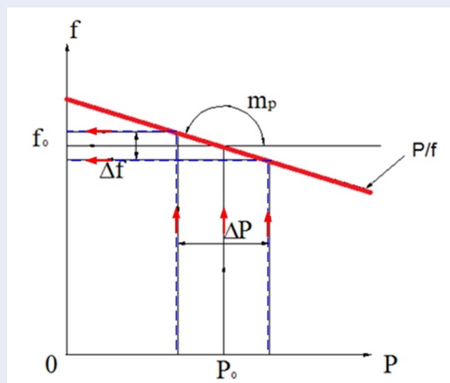

Figure 4: Droop P/f plot

Equations (5) show that: Q depends on voltage V. From there, we can establish Q/V droop controller to control the reactive power of the inverters as Eq. (7) (Figure 23):
The droop graph of equation (7) is drawn in Figure 5. Figure 5 shows that when the power Q changes, the voltage V also changes. If the load increases significantly, the voltage will decrease significantly compared to the rated value and vice versa.

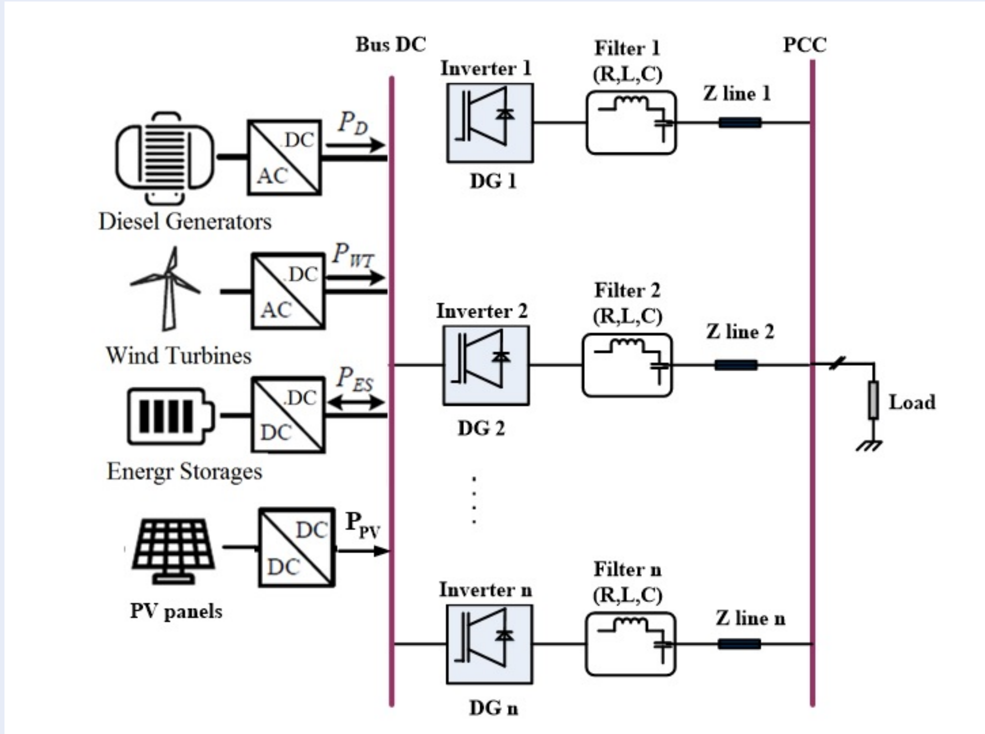

Figure 1: Common structure of an independent microgrid

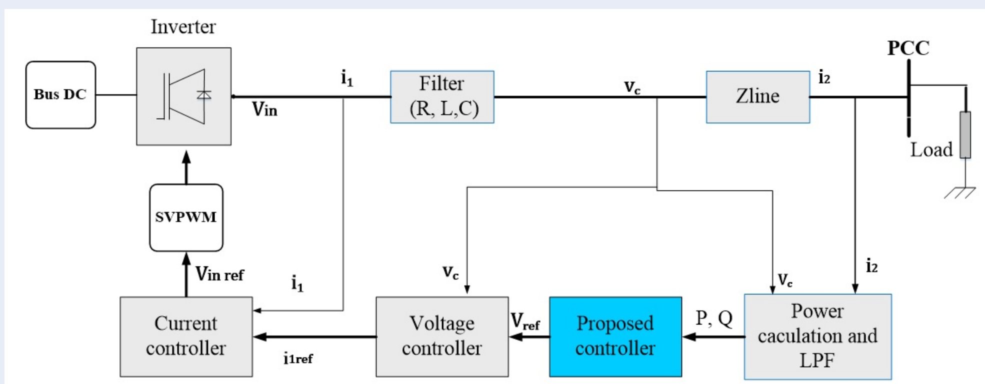

Figure 2: Block diagram of the proposed controller for an inverter in islanded microgrid

Where:

V_0 is the nominal amplitude voltage.

f_0 is the nominal frequency.

V is the measured amplitude voltage of the inverter.

f is the measured frequency of the inverter.

P_0 is the nominal active power of the inverter.

Q_0 is the nominal reactive power of the inverter.

m_p and m_q are the droop coefficients, which are calculated as Eq. (8) (Figure 23):

DESIGN OF THE FUZZY LOGIC CONTROLLER

Figure 4 and Figure 5 show that when the power consumption of the load changes, the frequency and voltage also change. If the load increases significantly, the frequency and voltage will decrease significantly compared to the rated value and vice versa. Dividing the power to the inverters according to the rated ratio is done by expression (8). We see that expression (8) has

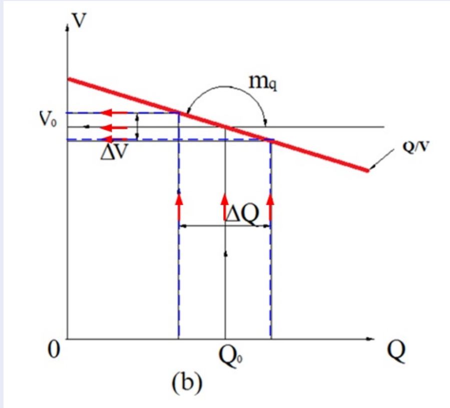

Figure 5: Droop Q/V plot

a constant value for each inverter, so the slopes of the P/f and Q/V droop curves do not change during operation. In fact, the load always changes in real time, which will lead to a situation where the voltage and frequency of the microgrid deviate too much from the rated value. This is also something we do not want. Therefore, this article provides a method to change the slope of the drop graph using fuzzy logic.

Equations (6), (7) and Figures 4 and 5 show that: a change in the active power of the consumed load (ΔP) will cause a corresponding change in frequency (Δf). Similarly, a change in the reactive power of the consuming load (ΔQ) will cause a corresponding change in voltage (ΔV). If these changes are significant, it will create unsatisfactory voltage quality in the microgrid. It may also cause balanced currents to flow in the inverters, which will cause damage to the inverters.

$V=V_0$ and $f=f_0$ can only be obtained when $Q=Q_0$ and $P=P_0$.

The equations (6) and (7) show that the power-sharing for inverters depends on the slope coefficients determined in equation (8). Figures 4 and 5 shows that the frequency at the output of the inverter changes according to the active power of the load and the voltage at the output of the inverter changes according to the reactive power of the load; The graph of droop P/f and Q/V in (6) and (7) have slopes that depend on (8). When the slopes (8) change, the power sharing will change accordingly. Therefore, this paper proposes a method to shift the slope coefficients m_p and m_q according to changes in the load instead of fixing them according to the equation (8).

In the conventional droop method, the slope coefficients m_p and m_q are fixed according to equation (8). When the load increases or decreases sharply, the frequency and voltage at the output of the inverter will deviate much from the value of its norm. In the proposed method, the slope coefficients m_p and m_q are adjusted to change according to the load. When the load increases or decreases sharply, the frequency and voltage at the output of the inverter will deviate less than with the conventional droop method.

The slopes m_p and m_q of the P/f and Q/V curves are varied by the fuzzy controller. The block diagram for the proposed droop-fuzzy logic controller is shown in Figure 5. Figure 6 is combined from equations (6), (7) and fuzzy-logic block to adjust the slope coefficients m_p and m_q. Whereas the conventional droop controller is implemented according to equations (6) and (7), m_p and m_q are fixed according to formula (8) as the Figure 7. Therefore, the conventional droop controller will give control results with larger voltage and frequency deviation than the proposed method.

Design of fuzzy controller to adjust mp slope:

This fuzzy controller has two inputs and one output :

The first input is the difference between the actual value and the rated value of the active power: $e_p = P - P_0$

The second input is the rate of change of active power over time: dP/dt

The output of this controller is the slip coefficient m_p.

Select language variable for input signal:

Language variable for e_p input:

NB: more negative; NS: less negative; ZE: equal zero; PS: less positive; PB: much positive

Language variable for dP/dt input:

N: negative; Z: zero; P: positive

We can choose more language variables for input and output for better tuning.

Select value domain for input signal:

Depending on the change of actual load capacity compared to the rated capacity value, we choose the appropriate value range.

Select value domain for e_p input: [-1000 1000]

Depending on the rate of increase or decrease of the actual load capacity, we choose the appropriate value range.

Select value domain for dP/dt input: [-100 1000]

Based on the sliding coefficient calculation expression (8), we choose the value range for the m_p output. Usually the m_p value is very small, so we choose many language variables for the output to make the adjustment more accurate.

Select value domain for m output: [0; $5.e^{-4}$]

Language variable for m output:

A1, A2, A3: small; B1, B2, B3: medium; C1, C2, C3: big

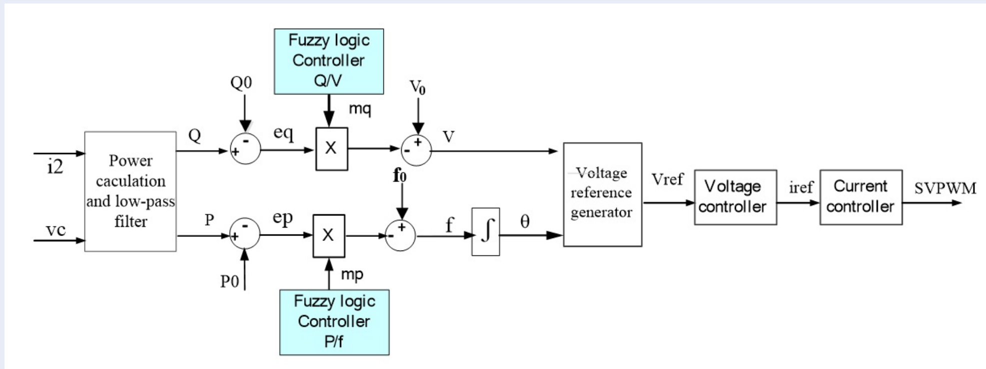

Figure 6: The proposed controller

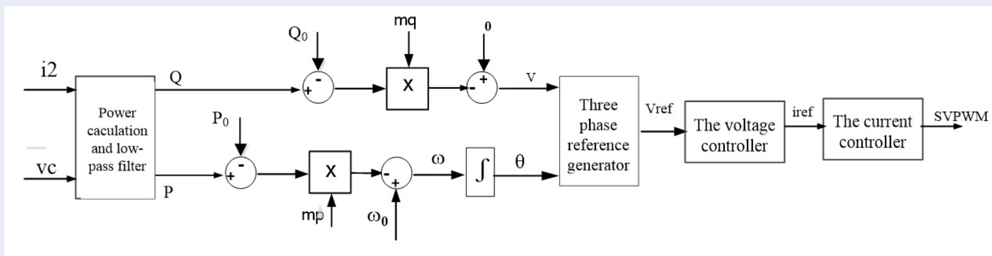

Figure 7: The conventional controller

Choose membership functions for the inputs:

We can choose a membership function of triangular or trapezoidal shape for the input as shown in Figures 8 and 9. We can choose a bar-shaped membership function for the output as shown in Figure 10.

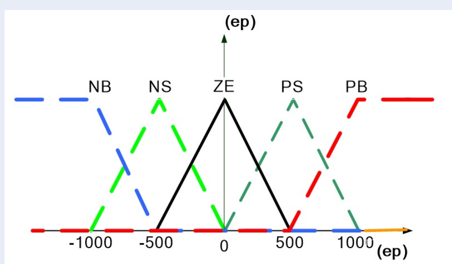

Figure 8: Membership function of input e_p

Choose membership functions for the output :

We can choose a membership function that is triangular, trapezoidal, or linear.

Design of fuzzy controller to adjust m

This fuzzy controller has two inputs and one output :

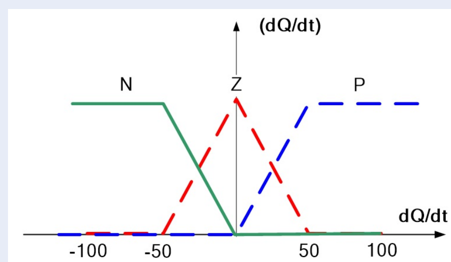

Figure 9: Membership function of input dP/dt

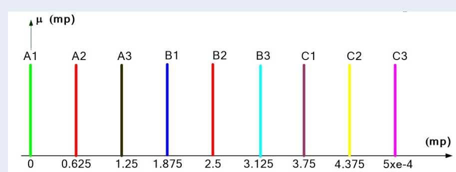

Figure 10: Membership function of output m_p

The first input is the difference between the actual value and the rated value of the reactive power: $e_q = Q - Q_0$

The second input is the rate of change of reactive power over time: dQ/dt

The output of this controller is the slip coefficient m_q.

Select language variable for input signal:

Language variable for e_q input:

NB: more negative; NS: less negative; ZE: equal zero; PS: less positive; PB: much positive

Language variable for dQ/dt input:

N: negative; Z: zero; P: positive

We can choose more language variables for input and output for better tuning.

Select value domain for input signal:

Depending on the change of actual load capacity compared to the rated capacity value, we choose the appropriate value range.

Select value domain for e_q input: [-1000 1000]

Depending on the rate of increase or decrease of the actual load capacity, we choose the appropriate value range.

Select value domain for dQ/dt input: [-1000 1000]

Depending on the rate of increase or decrease of the actual load capacity, we choose the appropriate value range.

Select value domain for dQ/dt input: [-100 1000]

Based on the sliding coefficient calculation expression (8), we choose the value range for the m_q output. Usually the m_p value is very small, so we choose many language variables for the output to make the adjustment more accurate.

Select value domain for m output: [0; 5.e^{-4}]

Language variable for m output:

A1, A2, A3: small; B1, B2, B3: medium; C1, C2, C3: big

Choose membership functions for the inputs:

We can choose a membership function of triangular or trapezoidal shape for the input as shown in Figure 11 and Figure 12. We can choose a bar-shaped membership function for the output as shown in Figure 13.

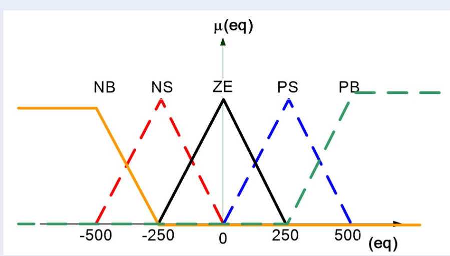

Figure 11: Membership function of input e_q

Choose membership functions for the output :

We can choose a membership function that is triangular, trapezoidal, or linear.

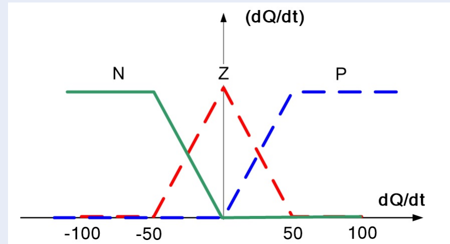

Figure 12: Membership function of input dQ/dt

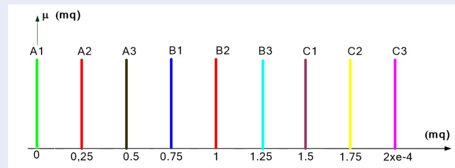

Figure 13: Membership function of output m_q

Define control rules:

Equations (6), (7), (8) and Figures 4 and 5 show them:

If $Q > Q_0$ then $V < V_{0,}$ In order for V to get close to V_0, we have to control to decrease the slope mq, which means we have to control to increase the angle α.

If $Q < Q_0$ then $V > V_{0,}$ In order for V to get close to V_0, we have to control to decrease the slope mq, which means we have to control to increase the angle α.

If $P > P_0$ then $f < f_{0,}$ In order for f to get close to f_0, we have to control to decrease the slope mp, which means we have to control to increase the angle α.

If $P < P_0$ then $f > f_{0,}$ In order for f to get close to f_0, we have to control to decrease the slope mp, which means we have to control to increase the angle α.

On the other hand, we rely on the language variables, the range of values, the membership function of the input and the output, we can set up the control rules as shown in Table 1.

If e_p = NB ($P << P_0$) and = N (P is decreasing) then we choose m_p output as A1.

If e_p = NS ($P << P_0$) and = N (P is decreasing) then we choose m_p output as B1.

If e_p = ZE ($P = P_0$) and = N (P is decreasing) then we choose m_p output as C1.

If e_p = PS and dP/dt = N then we choose m_p output as B3.

If e_p = BP and dP/dt = N then we choose m_p output as A3.

If e_p = NB and dP/dt = Z then we choose m_p output as A2.

If e_p = NB and dP/dt = P then we choose m_p output as A3.
If e_p = NS and dP/dt = Z then we choose m_p output as B2.
If e_p = ZE and dP/dt = Z then we choose m_p output as C2.
If e_p = PS and dP/dt = Z then we choose m_p output as B2.
If e_p = PB and dP/dt = Z then we choose m_p output as A2.
If e_p = NS and dP/dt = P then we choose m_p output as B3.
If e_p = ZE and dP/dt = P then we choose m_p output as C3.
If e_p = PS and dP/dt = P then we choose m_p output as B1.
If e_p = PB and dP/dt = P then we choose m_p output as A1.
Similarly, we can choose the control law for the fuzzy controller m_q
Choose the composition rule according to the Sum-Prod principle. Defuzzification by the centroid method.

Calculation and low-pass filter

The instantaneous power p and q are calculated according to the instantaneous value of the current flowing on the line (i_2) and the voltage at the beginning of the line (v_c) in a stationary *dq0* frame as Eq. (9) and (10) (Figure 23):

The current controller and voltage controller

Based on the equivalent circuit shown in Figure 14, we set up these controllers.
Where:
R (Ω) and L (H) are resistor and inductance of the line.
R_f (Ω) and L_f (H) are resistor and inductance of the filter (H).
Applying Kirchhoff's laws to the circuit of Figure 14, we have the following equations (11) and (12) (Figure 23):
Projecting equation (12) onto the coordinate system dq0. The voltage bias is eliminated by the PI controller on both the d-axis and the q-axis, the d-axis voltage bias is added with a feedback component ($-\omega C v_{cq}$), and a voltage bias on the q-axis is added feedback component($\omega C v_{cd}$). According to [15], the capacitance of the filter capacitor is usually very small, so the C dv_{cd}/dt and C dv_{cq}/dt components are ignored, the equations (11) can be written as Equation (13) and (14) (Figure 23).
Equations (13) and (14) are the voltage controller.
Projecting equation (12) onto the coordinate system dq0. The current bias is eliminated by the PI controller on both the d-axis and the q-axis, the d-axis current bias is added with a feedback component ($-\omega L_f i_{1q}$), and a current bias on the q-axis is added feedback component ($\omega L_f i_{1d}$). According to [15], the inductance and resistance of the filter capacitor is usually very small, so the (L_f (di_{1d})/dt + R_f i_{1d}) and (L_f(di_{1q})/dt + $R_f i_{1q}$) components are ignored, the equations (12) can be written as equation (15) and (16) (Figure 23):
Equations (15) and (16) are the current controller.

SIMULATION RESULT AND DISCUSSION

Simulate power control for a microgrid consisting of three inverters connected in parallel using Matlab/simulink software. Simulations are performed by the conventional controller and the proposed controller to compare the results. Simulation parameters are given in Table 1.

Case 1:

Power sharing simulation for two inverters in an independent microgrid is performed using the proposed controller.

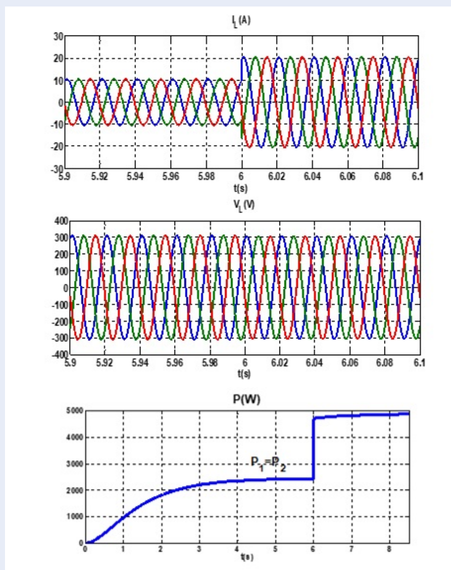

Figure 16: The waveform of voltage and current at the load

Figure 15a and 15b show that for an erroneous value of active power (e_p) at the input of the fuzzy logic

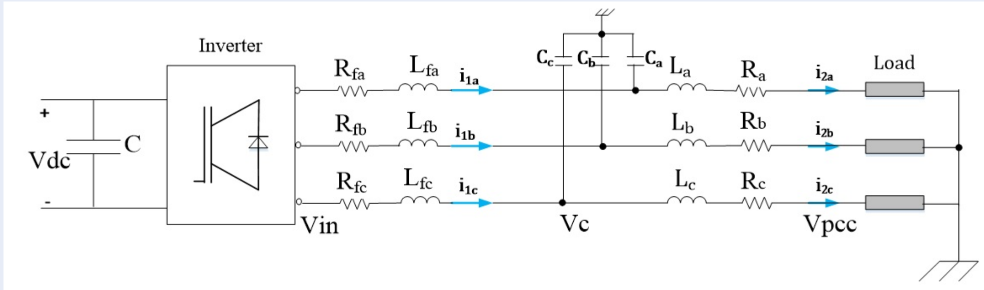

Figure 14: Equivalent schematic of inverters connected to a load.

Table 1: SIMULATION PARAMETERS

Parameters	Values	Parameters	Values
DC link voltage Vcd (V)	600	Nominal frequency f_0 (Hz)	50
Filter L_f (mH)	4.2	Nominal power (kVA)	4
Filter R_f (Ω)	0.1	Nominal voltage $V_{AC,p}$ (V)	310
Filter C (mF)	2.2	m_q (V/Var)	1.05e-4
f_z(kHz)	10	m_p (rad/s /W)	1e-4
k_{pv}	0.1	k_{pi}	10
K_{iv}	0.05	k_{ii}	1
Line impedances			
L_1(mH)	1	R_1(Ω)	1.2
L_2(mH)	0.8	R_2(Ω)	0.9
L_3(mH)	0.5	R_3(Ω)	0.7

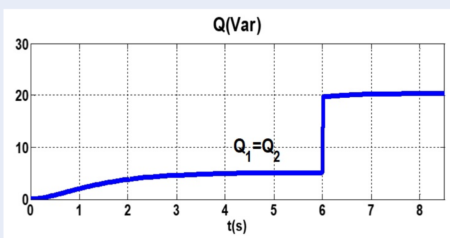

Figure 17: Output power of two inverters

block, there will be a corresponding slope coefficient m_p at the output of the fuzzy logic block. The value of m_p is within the specified range selected (the range of values is selected by formulas (6), (7), and (8)). On the other hand, when the e_p deviation decreases, m_p increases (increases in the selected value range), and vice versa when the e_p deviation increases (from 6s onwards) the m_p decreases. These results are completely consistent with the fuzzy control law established. Figure 15c shows that when the slope coefficient m_p changes, the frequency at the output of the Droop-fuzzy logic controller or the output frequency of the inverter also changes accordingly, the curve of frequency shows as the load increases then the frequency decreases, which is also completely consistent with the equation (6) and power curve in the Figure 4. The f value is also calculated according to m_p and e_p in equations (7), (8), and the frequency deviation from the norm is calculated in Table 2. Table 2 shows that the frequency deviation is very small, this result is due to the fuzzy-logic controller that controls to change m_p when the load changes. As we see in the Figure 4, if we don't change the slope of the droop curve P/f as the load changes, then a power deviation ΔP will give a corresponding frequency deviation Δf, and when the load changes more, then the Δf will be large. Same as above, Figures 15d and 15e show that for a deviation of reactive power e_q, it will give a value of slope

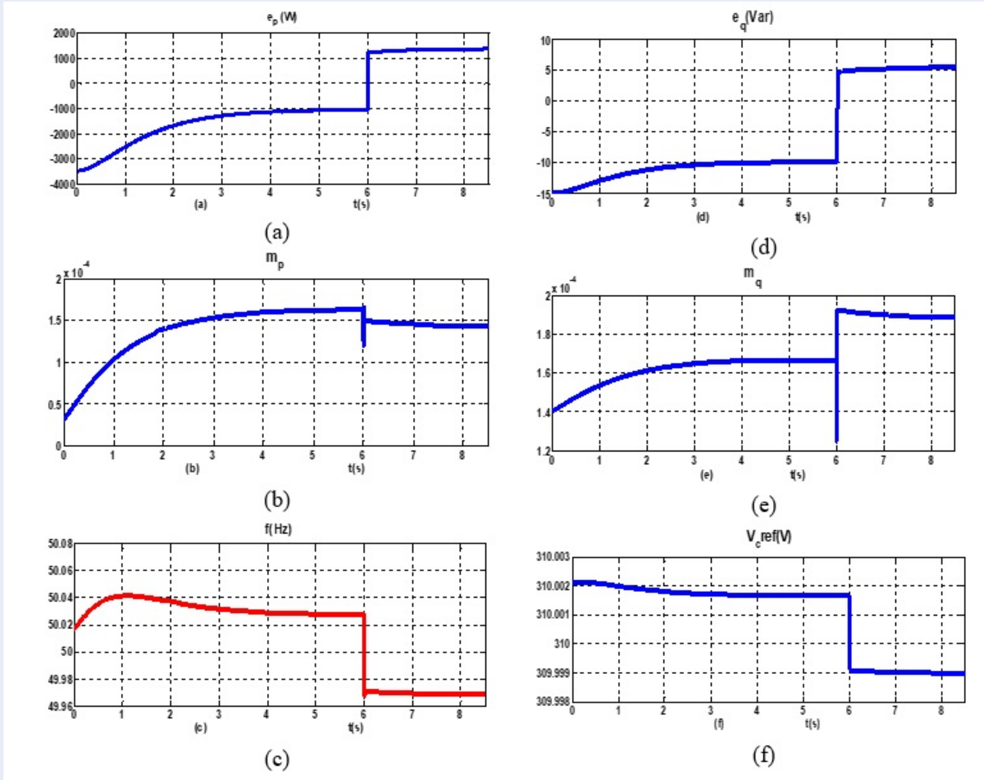

Figure 15: The graph showing the change of slip coefficients (mp, mq) and frequency and voltage as the load increases

coefficient m_q in the selected range of values, and we see that when the deviation e_q decreases, the slope coefficient m_q increases and vice versa, at t=6s, the e_q deviation continues to decrease compared to the previous one, so the slope coefficient m_q at continues to increase. This is completely consistent with the fuzzy control law established. Figure 15f shows that when the slope coefficient m_q changes, the voltage at the output of the Droop-fuzzy logic controller or the output voltage of the inverter also changes accordingly, which is also completely consistent with equation (7) and power curve in Figure 4b. The voltage value is also calculated according to m_q and e_q in formula (7), (8), voltage deviation from the norm is calculated in Table 2. Table 2 shows that the voltage difference is very small, to get this result is because we control the slope of the power characteristic curve when the load changes. As we see in Figure 5, if we do not change the slope of the power curve Q/V when the load changes, then a power deviation ΔQ will give a corresponding voltage deviation ΔV, and when the load changes more, then theΔV will be large.

Figures 16 and 17 show the Droop-fuzzy logic control method for a good dynamic response as soon as the load changes and the current and voltage stabilizes well right after the load changes. The output power of the inverters is divided exactly in a 1:1 ratio.

The simulation results above show that the proposed method controls the correct sharing power for the inverters and reduces the voltage and frequency deviation when the load changes suddenly, improving the quality of the power supply for the load, and a good dynamic response. The proposed method has overcome the disadvantages of the conventional or improved droop methods because the slope of this power curve is always fixed, so when the load changes, the voltage and frequency deviations cannot be adjusted to improve power quality.

Case 2:

Two inverters have the same rated power, they are connected in parallel, Simulate power division by the proposed method.

Figure 18 shows that the proposed controller gives good power division results, the power division results in the time period from 0s to 5s have the following deviations:

Table 2: Table of results for frequency and voltage deviation from rated value

Load parameters	(Δf=f0-f)	(ΔV=V0-V)
Z1 = 20+j3 (W)	Δf=50-50.0276 = -0.276(Hz)	ΔV=310-310.0016 = -0.0016(V)
Z2 = 10+j2 (W)	Δf=50-49.9686 = 0.0314(Hz)	ΔV=310-309.98 = 0.002 (V)

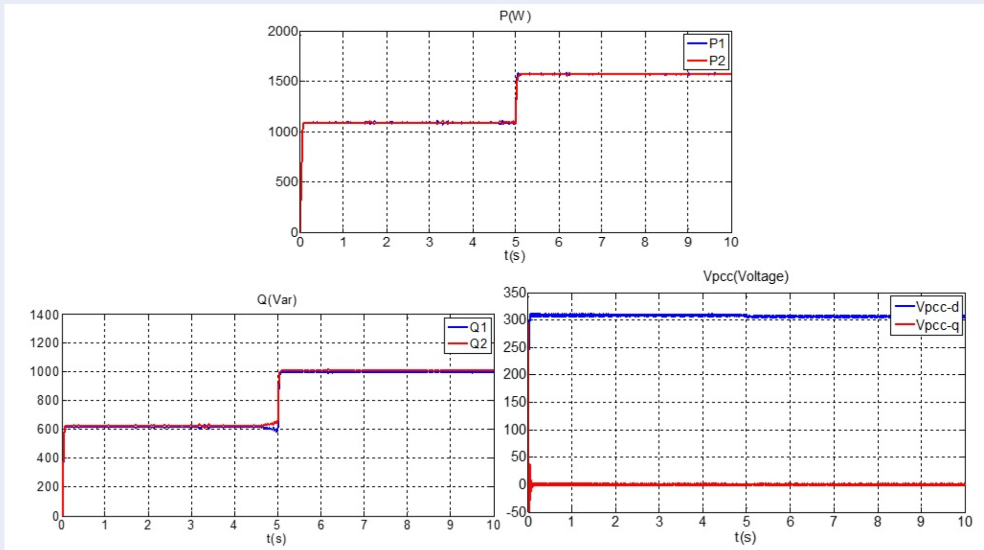

Figure 18: The graph of sharing active power, reactive power, and voltage at load when simulated by the proposed droop-fuzzy controller

$e_p\% = (P_i - P^*_i)/(P^*_i).100\% = (1118-1110)/(1110).100\% = 0.72\ \%$

The error of sharing the reactive power of inverters for the period from 0s to 5s:

$e_q\% = (Q_i - P^*_i)/(Q^*_i).100\% = (625-620)/(620).100\% = 0.8\ \%$

This shows that the proposed method gives highly accurate power division results.

Figure 19 shows that the conventional droop controller gives poor power-sharing results, the error is very large when sharing reactive power. The error of sharing the reactive power of inverters for the period from 0s to 5s:

$e_q\% = (Q_i - P^*_i)/(Q^*_i).100\% = (644-620)/(620).100\% = 3.8\ \%$

The voltage graph in Figure 18 also shows that the voltage deviation given by the proposed drooping fuzzy controller is very small, especially as the load increases, the voltage drop is smaller than the voltage graph in Figure 19.

Case 3:

Use the proposed method to divide the power between the two inverters according to the rated power ratio of 2:1, $P_{dm1}=2P_{dm2}$

Figure 20 shows that the proposed controller has given the correct power-sharing results with the rated power ratio 2:1, its transient response and steady-state response are also very good, and the time steady-state set up early.

Case 4:

Use the proposed method to divide the power between the three inverters according to the rated power ratio of 1:1:1, $P_{dm1}=P_{dm2}=P_{dm3}$.

Figure 21 shows that the proposed controller gave the correct power-sharing results with the rated power ratio 1:1:1, its steady-state response is very good, and the time steady-state is set up early.

Case 5:

Use the proposed method to divide the power among the three inverters according to the rated power ratio

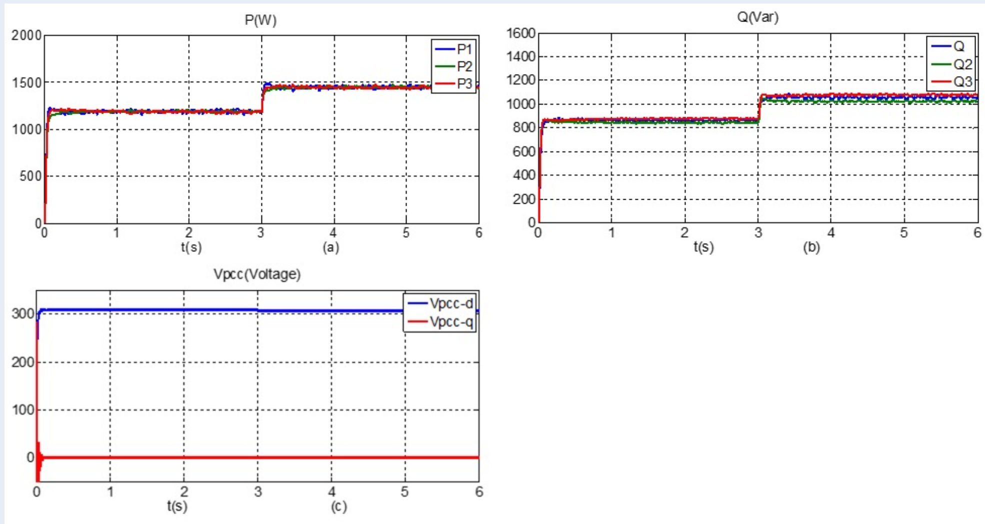

Figure 22: The graph of sharing active power, reactive power, and voltage at load by the proposed droop-fuzzy controller

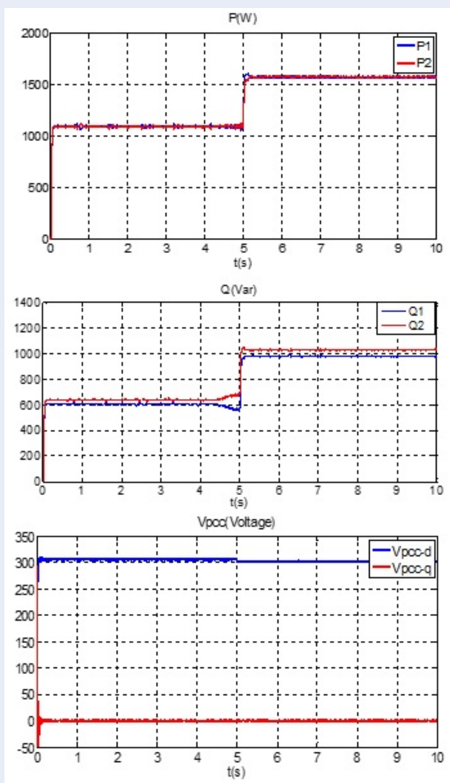

Figure 19: The graph of sharing active power, reactive power, and voltage at load when simulated by the conventional droop

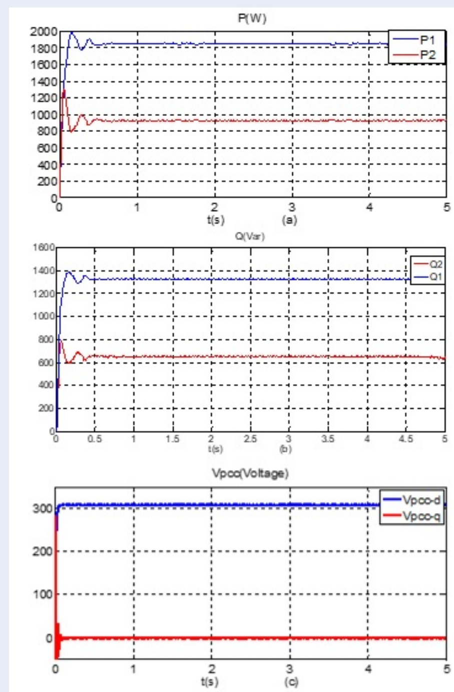

Figure 20: The graph of sharing active power, reactive power, and voltage at load by the proposed droop-fuzzy controller

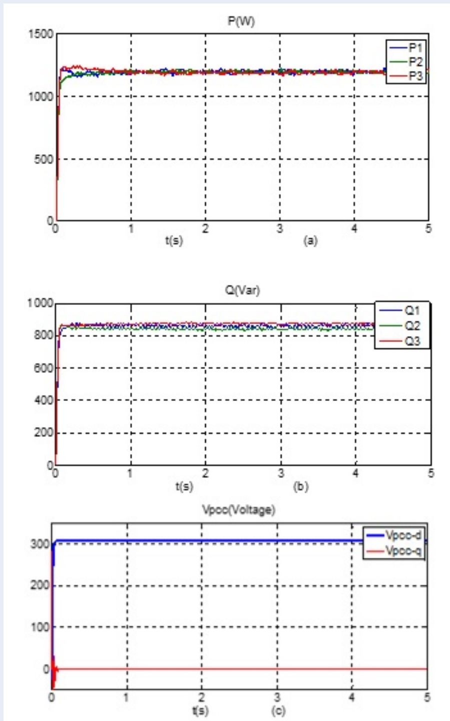

Figure 21: The graph of sharing active power, reactive power, and voltage at load by the proposed droop-fuzzy controller

of 1:1:1, the load varying in this case.

Figure 22 shows that the proposed controller gave the correct power-sharing results with the rated power ratio even when the load has changed.

The above simulation results show that the proposed controller gives good results, negligible deviation, and relatively early setup time. Good voltage quality, low voltage and frequency deviation.

CONCLUSION

In this paper, a sliding coefficient adjustment method using fuzzy logic is proposed, improving the traditional droop controller. This innovation allows to significantly improve the accuracy of power sharing for inverters in the microgrid, improve the quality of voltage supplied to loads, and reduce frequency deviation. The advantages of the proposed method were verified by simulation for microgrids with two and three inverters.

CONFLICT OF INTEREST

There is no conflict of interest regarding this manuscript.

AUTHOR CONTRIBUTION

Xuan Hoa Thi Pham have writen this entire paper.

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$$\tilde{S}=\dot{V}.I^{*}=\dot{V}.\left(\frac{\dot{V}-\dot{V}_{PCC}}{\dot{Z}}\right)^{*}=V.e^{j\delta_1}\left(\frac{Ve^{j\delta_1}-V_{PCC}e^{j\delta_2}}{Ze^{j\theta}}\right)^{*}=P+jQ \quad (1)$$

$$\sin\delta=\frac{XP-RQ}{VV_{PCC}} \quad (2)$$

$$V-V_{PCC}\cos\delta=\frac{RP+XQ}{V} \quad (3)$$

$$\delta=\frac{XP}{VV_{PCC}} \quad (4)$$

$$V-V_{PCC}=\frac{XQ}{V} \quad (5)$$

$$f=f_0-m_p(P-P_0) \quad (6)$$

$$V=V_0-m_q\left(Q-Q_0\right) \quad (7)$$

$$m_p=\frac{f_0-f_{min}}{P_{max}-P_0}\ ; \quad m_q=\frac{V_0-V_{min}}{Q_{max}-Q_0} \quad (8)$$

$$p=\frac{3}{2}(i_{2d}v_{cd}+i_{2q}v_{cq}) \quad (9)$$

$$q=\frac{3}{2}(i_{2d}v_{cq}-i_{2q}v_{cd}) \quad (10)$$

$$\begin{cases} i_1=i_2+C\dfrac{dv_c}{dt}+i' & (11)\\ v_{inv}=L_f\dfrac{di_1}{dt}+R_f i_1+v_c & (12)\end{cases}$$

$$\begin{cases} i_{1d}=k_{pv}\left(v_{cd}^{*}-v_{cd}\right)+k_{iv}\int\left(v_{cd}^{*}-v_{cd}\right)dt+i_{2d}-\omega C v_{cq} & (13)\\ i_{1q}=k_{pv}\left(v_{cq}^{*}-v_{cq}\right)+k_{iv}\int\left(v_{cq}^{*}-v_{cq}\right)dt+i_{2q}+\omega C v_{cd} & (14)\end{cases}$$

$$\begin{cases} v_{invd}=k_{pi}\left(i_{1d}^{*}-i_{1d}\right)+k_{ii}\int\left(i_{1d}^{*}-i_{1d}\right)dt-\omega L_f i_{1q}+v_{cd} & (15)\\ v_{invq}=k_{pi}\left(i_{1q}^{*}-i_{1q}\right)+k_{ii}\int\left(i_{1q}^{*}-i_{1q}\right)dt+\omega L_f i_{1d}+v_{cq} & (16)\end{cases}$$

Figure 23: Equation

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Bài nghiên cứu

Bộ điều khiển điện áp và tần số cho các bộ nghịch lưu kết nối song song trong microgrid sử dụng logic mờ

Phạm Thị Xuân Hoa*

TÓM TẮT

Hiện nay, năng lượng điện được tạo ra từ các nguồn năng lượng tái tạo đang được sử dụng ngày càng rộng rãi. Các nguồn năng lượng này tập hợp lại và hình thành nên một lưới điện siêu nhỏ. Lưới điện siêu nhỏ có thể hoạt động ở chế độ độc lập hoặc được kết nối với lưới điện. Khi lưới điện siêu nhỏ hoạt động ở chế độ độc lập, nó phải được điều khiển để ổn định tần số và điện áp trong lưới điện siêu nhỏ. Bài viết này đề xuất một phương pháp điều khiển công suất cho các bộ nghịch lưu trong lưới điện siêu nhỏ, mục đích của phương pháp đề xuất là ổn định tần số và điện áp trong lưới điện siêu nhỏ. Bên cạnh đó, phương pháp điều khiển đề xuất cũng điều chỉnh điện áp và tần số để cải thiện chất lượng điện năng trong lưới điện siêu nhỏ. Phương pháp đề xuất này dựa trên logic mờ để dịch chuyển độ dốc của đường cong đặc tính droop theo tải. Mục đích của phương pháp đề xuất là cải thiện độ chính xác của việc chia sẻ công suất cho các bộ nghịch lưu trong lưới điện siêu nhỏ và nó cũng làm giảm độ lệch điện áp và tần số trong lưới điện siêu nhỏ, nó cải thiện chất lượng điện năng trong lưới điện siêu nhỏ. Trọng tâm của bài báo này là cải thiện chất lượng điện áp kết hợp với chia sẻ công suất giữa các bộ nghịch lưu để ổn định điện áp và tần số trong lưới điện siêu nhỏ bằng cách cải tiến bộ điều khiển droop truyền thống, vì bộ điều khiển droop đơn giản, dễ triển khai, không cần sử dụng mạng truyền thông, nhược điểm của bộ điều khiển droop truyền thống là hệ số droop cố định. Bộ điều khiển được đề xuất có thể điều chỉnh hệ số droop theo sự thay đổi tải dựa trên suy luận logic mờ, bộ điều khiển đơn giản và có thể áp dụng cho các lưới điện siêu nhỏ phức tạp với nhiều nguồn điện và nhiều bộ nghịch lưu được kết nối song song. Bộ điều khiển đề xuất được mô phỏng cho một lưới điện siêu nhỏ độc lập với ba bộ biến tần được kết nối song song bằng phần mềm Matlab/Simulink để chứng minh tính phù hợp của phương pháp được đề xuất.

Từ khoá: Điều khiển droop, chia sẻ công suất, điều khiển điện áp, điều khiển tần số, logic mờ

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