A VOLTAGE MODE CONTROL FOR SINGLE-PHASE INVERTERS IN PARALLEL OPERATION

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Abstract

The active and reactive power, P and Q, are important variables when dividing the load for parallel connected inverters using a droop controller. P and Q are calculated based on the transformer output voltage value and the load current. However, when it comes to sharing the nonlinear load power, low pass filters with very low cut-off frequency are used to eliminate harmonics of the load current for increasing accuracy when calculating P and Q. These filters slow down the dynamics of the system, reduce the reliability and cause control errors. This paper uses the DSOGI algorithm to replace the low pass filter, increasing the dynamics and stability of the system. The voltage mode control with a simple observer (DOB) can ensure that the quality of the inverters output voltage and current follows an IEEE standard. The algorithms were tested through simulation on Plecs, with system consists of 2 one phase inverters working in parallel.

Keywords: *Parallel inverters; droop control; vitual impedance; double second order generalized integrator (DSOGI).*

1. Introduction

Microgrids [1] are considered of particular interest when it is necessary to integrate renewable energy sources and storage devices in Fig. 1. For the islanding operation of AC micogrids, two important tasks are to share the load demand among multiple parallel connected inverters proportionately, and maintain the voltage and frequency stabilities [2, 3]. The droop control method is adopted to achieve wireless control [4]. The wireless control technique is based on the well-known droop method, which consists in introducing P-ω and Q-V schemes into the inverters, in order to share properly the power drawn to the loads. However, the power sharing accuracy is highly sensitive to the output impedance of inverter. Besides, droop characteristic presents several drawbacks: Frequency and voltage have deviation in islanding mode, Harmonic

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loads, The different and unknown line impedances, Fluctuant and changeable output power of DGs... To overcome these drawbacks and minimize the circulating current under all situations, a typical and popular approach is based on virtual output impedance method. In this system, a virtual output impedance is used in droop control to increase stability when sharing loads, especially for nonlinear load or unequal line impedances. To ensure the efficient steady-state and dynamic performance, the controller of each inverter includes an output voltage loop [4], or an output voltage loop and an output current compensation loop [5]. The quality of the inverters output voltage and current follows the IEEE standard by the proposed controller [6].

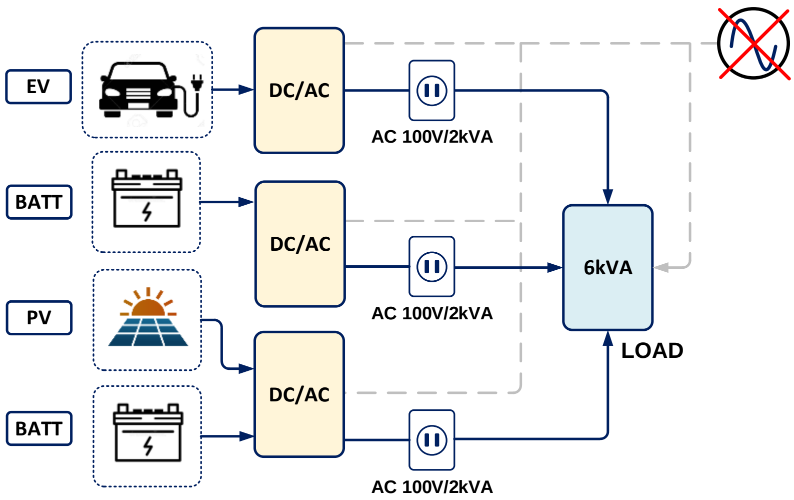


Fig. 1. The islanding operation of inverters

2. The control strategies for inverters in parallel operation

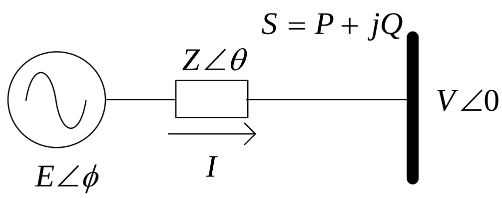


Fig. 2. Equivalent circuit of an inverter connected to an AC bus.

Fig. 2 shows the equivalent circuit of an inverter connected to an AC bus, P and Q are the active and the reactive power, respectively, which are given by:

$$\begin{cases} P = \dfrac{EV}{Z}\cos(\theta - \phi) - \dfrac{V^2}{Z}\cos\theta \\ Q = \dfrac{EV}{Z}\sin(\theta - \phi) - \dfrac{V^2}{Z}\sin\theta \end{cases} \tag{1}$$

where E and V are the amplitudes of the inverter output voltage and the common bus voltage, ϕ is the power angle, and Z and θ are the magnitude and the phase of the output impedance. A conventional assumption is to consider that the output impedance of the inverters is mainly inductive ($\theta = 90^0$), which is often justified by the large filter-inductor value

$$\begin{cases} P = \dfrac{EV}{X}\sin\phi \approx \dfrac{EV}{X}\phi \\ Q = \dfrac{EV\cos\phi - V^2}{X} \approx \dfrac{EV - V^2}{X} \end{cases} \tag{2}$$

As a result, the conventional droop control strategy for inverters with an inductive takes the form

$$\begin{cases} \omega = \omega^* - m_i P \\ E = E^* - n_i Q \end{cases} \tag{3}$$

In [5, 6], the droop gains of P-ω and Q-V are determined

$$\begin{cases} m_i \le \dfrac{\omega_{\max} - \omega_{\min}}{P^*} = \dfrac{\Delta\omega}{P^*} \\ n_i \le \dfrac{E_{\max} - E_{\min}}{Q^*} = \dfrac{\Delta V}{Q^*} \end{cases} \tag{4}$$

where ω and E are the angular frequency and voltage amplitude references of a voltage source inverter (VSI), respectively. The ω^* and E^* represent values of ω and E at no load, and m_i and n_i are droop gains of P-ω and Q-V, respectively. P^* and Q^* are the rated active and reactive power. ω_{max} and ω_{min} are maximum and minimum values of the allowable angular frequency; and E_{max} and E_{min} are maximum and minimum values of the allowable voltage amplitude, respectively. $\Delta\omega$ and ΔV are frequency drop and voltage drop, respectively.

The instantaneous active (p) and reactive powers (q) are calculated as the product of the inverter output voltage and its orthogonal version with the output current, respectively.

$$\begin{cases} p = v_o i_o = v_{o\alpha} i_o \\ q = v_{o\perp} i_o = v_{o\beta} i_o \end{cases} \tag{5}$$

The quadrature voltage $v_{o\perp}$ is obtained by delaying v_0 by π/2, and the average active (P) and reactive powers (Q) by using LPFs [8] with a low cut-off frequency value f_c, to filter the multiple frequency components in the instantaneous powers.

When sharing linear loads, the value of f_c is usually set to one or two orders of magnitude lower than the inverter fundamental operating frequency, which determines the transient dynamic performance of the system. However, when the system supplies for a nonlinear load, the value of f_c needs to be reduced even more (usually to less than 1 Hz), for avoiding harmonic effects of output current. Conversely, the distortion in the current induces excessive ripple in the averaged powers, which in turn is translated to the droop references frequency and magitude voltage, and then to $v_r(t)$, causing bad operation of the system. This forces the droop method to operate at a very low dynamic velocity and degrades the system stability. Therefore, this work presents a method to calculate the average active (P) and reactive powers (Q) using second-order generalized integrators (SOGI) to face this problem with nonlinear loads. A double SOGI (DSOGI) is used to filter nonlinear load currents, obtaining outputs with less harmonics, increase the dynamic speed of the droop control, making the system stable under different conditions of load [9].

$$\begin{cases} P = \left(\dfrac{2\pi f_c}{s + 2\pi f_c} \right) p \\ Q = \left(\dfrac{2\pi f_c}{s + 2\pi f_c} \right) q \end{cases} \tag{6}$$

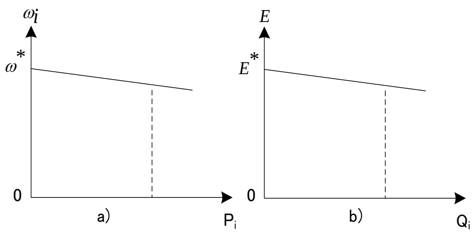


Fig. 3. Droop Characteristics.
a) P-ω characteristic, b) Q-E characteristic

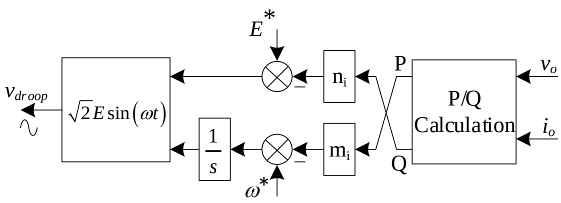


Fig. 4. Conventional droop control P-ω and Q-E scheme

A SOGI is a filter with one input, $v_i(t)$, and two outputs, $v_d(t)$ and $v_q(t)$, one has the same phase and the other one is delayed by π/2 from the input. The outputs of the SOGI filter

$$\begin{cases} H_d(s) = \dfrac{v_d(s)}{v_i(s)} = \dfrac{k_{SOGI}\omega_1 s}{s^2 + k_{SOGI}\omega_1 s + \omega_1^2} \\ H_q(s) = \dfrac{v_q(s)}{v_i(s)} = \dfrac{k_{SOGI}\omega_1^2}{s^2 + k_{SOGI}\omega_1 s + \omega_1^2} \end{cases} \tag{7}$$

where k_{SOGI} is the filter damping factor and ω_1 is the tuning center frequency.

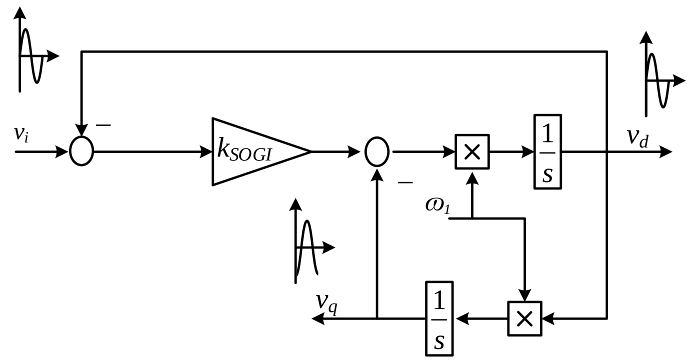


Fig. 5. Second order generalized integrators (SOGI)

DSOGI is a four-order filter that consists in the cascade connection of two SOGI filters. The DSOGI includes 2 blocks named SOGI3 and SOGI4 for filtering the harmonics of $i_o(t)$ means of its higher band-pass filter (BPF) capability and avoiding the noise effects of load current. Consequently, the instantaneous active (p) and reactive powers (q) are obtained as the product of the in-phase $v_o(t)$ or the quadrature $v_{o\perp}(t)$ voltages with the fundamental output current i_{OF}, respectively. This produces a result without the higher harmonics but only the second harmonic component. Later, the SOGI1 and SOGI2 blocks were used as in Fig. 6 [9] for removing only the double frequency components with the help of the subtracting blocks. Therefore, LPF filters can be removed, dynamic speed of system increased, also active power values and reactive power calculated with greater precision.

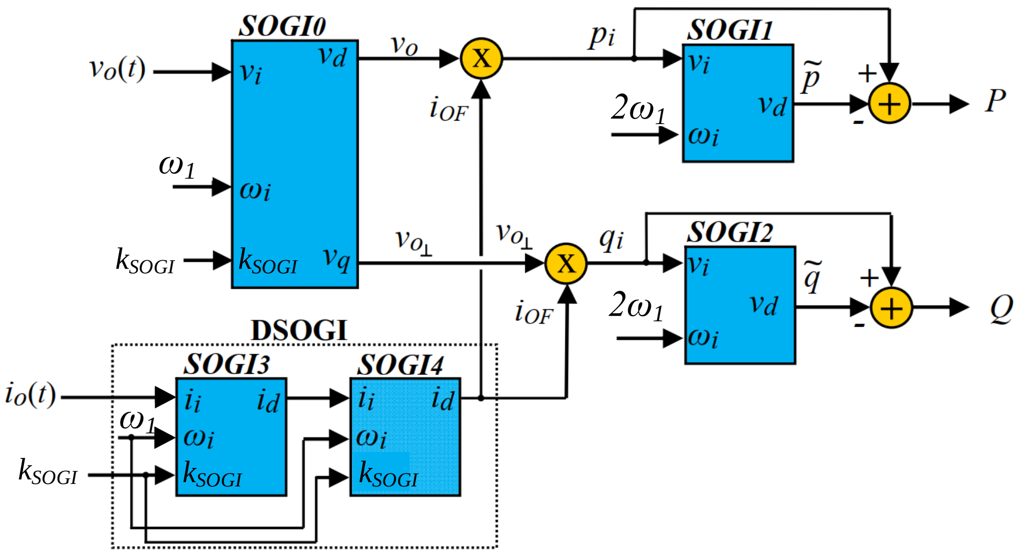


Fig. 6. Scheme for the proposed P-Q calculation based on a DSOGI approach.

In order to increase the stability of the system, reduce the impact of circulating currents, and to share linear and nonlinear loads, some approaches introduce a virtual impedance into the system by an additional control loop [8, 9], of the form

$$v_{oref} = v_{droop} - Z_v\left(s\right)i_o \tag{8}$$

where v_{droop} is the voltage reference delivered by the droop method and $Z_v(s)$ is the virtual output impedance.

A virtual inductive output impedance ($Z_v(s) = sL_v$) is implemeted by drooping the reference output voltage proportionally to the time derivative of the inverter output current. This loop increases the total inverter output inductive impedance, increasing thus the impedance between the inverter and the common bus line, and reducing the circulating current in the system. However, the virtual impedance is implemented by the time derivative of the inverter output current that can amplify the noise that is normally present in this current. As a result, the LPF is introduced into this loop to avoid the introduction of excessive noise into the system:

$$Z_v\left(s\right) = \frac{2\pi f_p}{s + 2\pi f_p} sL_v \tag{9}$$

f_p is the LPF cut-off frequency, it is chosen (150Hz÷300Hz).

Fig. 6 illustrates the parallel-connected inverters with wireless load-sharing control. A novel wireless controller is designed by using three nested loops: 1) The inner loop uses voltage feedback signal to generate control signals for the inverter; 2) The middle loop performs output impedance compensation for the system, using the virtual impedance method; 3) The outer loop is droop control, performs reactive and positive power calculations, finds out the reference value for the system to execute the load sharing process.

3. The voltage mode control for single-phase inverter

To compensate for the output voltage distortion, the high-gain DOB for the output voltage is applied for open-loop-based voltage control. The inverter output voltage total harmonic distortion is less than 5% even with linear load and non-linear load, whereas the constant output voltage is achieved regardless of load conditions [12]. To improve dynamic perpormance load voltage, the voltage loop is implemented as Fig. 7. Due to sinusoidal reference voltage, the output voltage must be added output of voltage regulator. The output voltage feedforward can be eliminated if the resonant is applied.

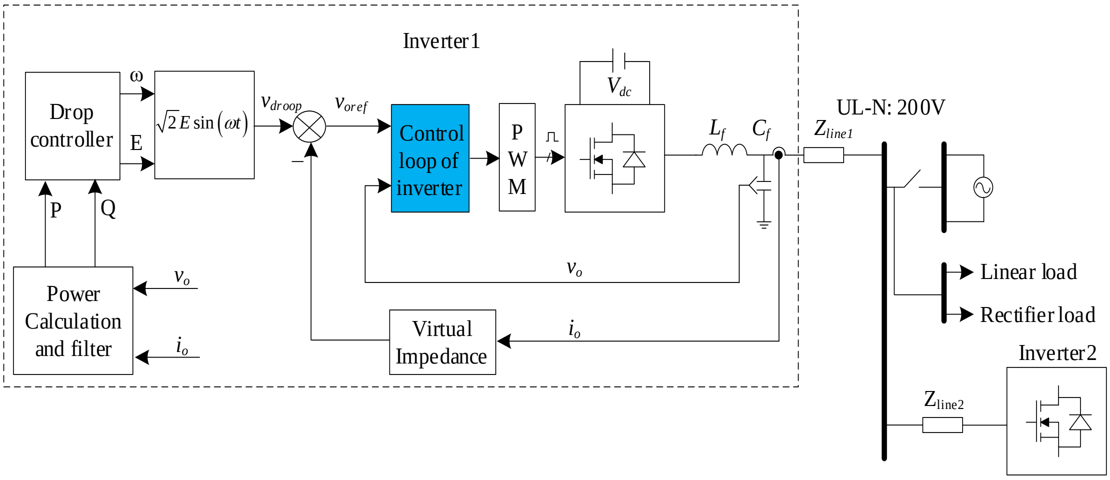


Fig. 7. Parallel connection system structure of wireless inverters in standalone

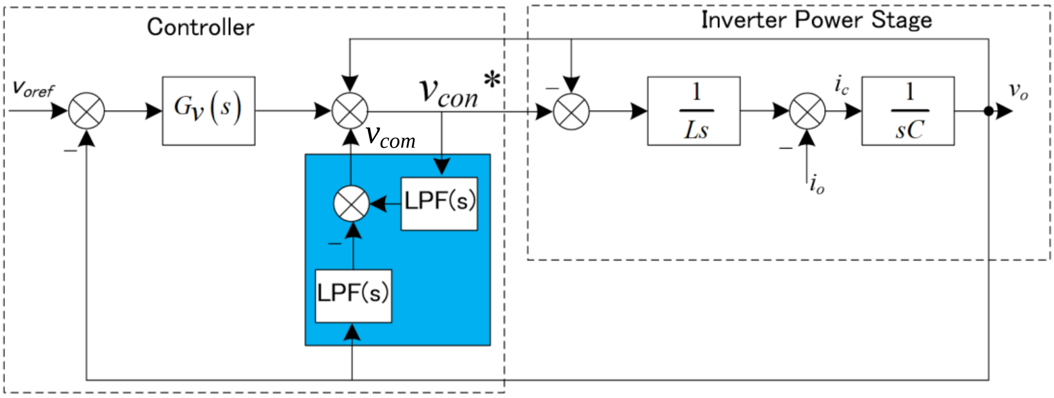


Fig. 8. The voltage mode control for single-phase inverter

The disturbance estimation value v_{com} is expressed by

$$v_{com} = \frac{\omega_{DOB}}{s+\omega_{DOB}} v_{con}^* - \frac{\omega_{DOB}}{s+\omega_{DOB}} v_o \tag{10}$$

where ω_{DOB} is the cut-off angular frequency of the DOB; v_{con}^* is the voltage command after the disturbance compensation; and v_o is the detection value of the filter capacitor voltage

where $kf_1 < f_{DOB} < f_{res\_LC}/n \left(n: 2 \sim 10,\ f_{DOB} = \omega_{DOB}/2\pi \right)$

Voltage controller is Lead-Lag compensator, using Lead compensator to improve phase margin (PM) at light load [13].

$$G_v(s) = K_c \frac{\left(1+\frac{s}{\omega_z}\right)}{\left(1+\frac{s}{\omega_p}\right)}\left(1+\frac{\omega_L}{s}\right) = K_c.G_{c1}(s) \qquad (11)$$

where ω_L is the time constant of the integrator. The maximum phase occurs at a frequency $f_{\varphi\max}$ given by the geometrical mean of the pole and zero frequencies:

$$f_{\varphi\max} = \sqrt{f_z f_p} \qquad (12)$$

To obtain the maximum improvement in phase margin, we should design our compensator so that the frequency $f_{\varphi\max}$ coincides with the loop gain crossover frequency f_c. The value of the phase at this frequency can be shown to be

$$\angle G_c\left(f_{\varphi\max}\right) = \tan^{-1}\left(\frac{1}{2}\left(\sqrt{\frac{f_p}{f_z}} - \sqrt{\frac{f_z}{f_p}}\right)\right) \qquad (13)$$

To optimally obtain a compensator phase lead of θ at frequency f_c, the pole and zero frequencies should be chosen as follows:

$$\begin{cases} f_z = f_c\sqrt{\dfrac{1-\sin\theta}{1+\sin\theta}} \\ f_p = f_c\sqrt{\dfrac{1+\sin\theta}{1-\sin\theta}} \end{cases} \qquad (14)$$

where $\theta = \angle G_c\left(f_{\varphi\max}\right)$, the phase of compensator at cut-off frequency f_c is expressed as:

$$\theta = -180^{\circ} + PM - \operatorname{arc} G_{vd}\left(j\omega\right)\Big|_{\omega=\omega_C} \qquad (15)$$

where *PM* is phase margin and selected by designer.

So that the inverted zero does not significantly degrade the phase margin, let us (somewhat arbitrarily) choose f_L to be one-tenth of the crossover frequency. The magnitude of the regulator gain is chosen to be unity at loop gain crossover frequency

$$K_c = \frac{1}{\left|G_{c1}\left(j\omega_c\right)\right| . \left|G_{vd}\left(j\omega_c\right)\right|} \qquad (16)$$

Parameters of the voltage controller are calculated in appendix by m-file Matlab.

4. Simulation results

Assume at the rated real and reactive power (rated power 4 kW, power factor is 0.85), the desired voltage drop ratio is 10% and the frequency drop ratio is 1%.

Load current at rated power (power factor is 0.85).

$$I_{load} = \frac{P}{U\cos\varphi} = \frac{4000}{200\times 0.85} = 23.5\text{A} \quad (17)$$

The voltage drops due to line impedance:

$$\Delta V = |Z_{line}| I_{load} \quad (18)$$

where $|Z_{line}| = \sqrt{R_{line}^2 + X_{line}^2}$

For Z_{line} = (0.434+j4.8e-3) Ω→ $|Z_{line}| \approx 0.434\Omega \rightarrow \Delta V = 0.434\times 23.5 = 10.2\text{V}$

For Z_{line} = (0.434+j4.8e-1) Ω→ $|Z_{line}| \approx 0.647\Omega \rightarrow \Delta V = 0.647\times 23.5 = 15\text{V}$

The maximum of voltage drop due to line impedance is less 10% rated voltage. So the line impedance must be limited by the desired voltage drop. The larger value of droop gains (m_i, n_i) improves power sharing accuracy, but increases the deviation of frequency/voltage from their rated values, resulting in a trade-off.

Parameters for inverters in parallel operation.

Symbol	Parameter	Inverter # 1	Inverter # 2
V_{dc}	DC link Voltage	350	350
Z_b	Base Impedance	10 Ω	10 Ω
Y_b	Base Admittance	0.1 S	0.1 S
L_f	Inductor (%Z = 0.5%)	160 µH	160 µH
C_f	Filter Capacitor (%Y = 2.52%)	8 µF	8 µF
f_s	Switching Frequency	100 kHz	100 kHz
T_d	Dead - Time	500 ns	500 ns
E^*	Nominal output voltage	200 Vrms	200 Vrms
ω^*	Nominal frequency	2π50 rad/s	2π50 rad/s
m_i	Frequency droop coefficient	7.85e-4 (rad/s)/W	7.85e-4 (rad/s)/W
n_i	Amplitude droop coefficient	0.0081 V/Var	0.0081 V/Var
L_v	Virtual inductor value	2 mH	2 mH
f_p	The cut-off virtual block	150 Hz	150 Hz
Z_{line}	Line impedance	(0.434+j4.8e-3) Ω	(0.29+j3.2e-3) Ω
k_{SOGI}	SOGI gain	1	1

Non-linear load is a single-phase diode rectifier diode-bridge, a bulky capacitor of 2040 µF, in parallel with a resistance of 10 Ω from 0 to 0.25s and 5 Ω from 0.25s to 0.5s. Linear load is an inductor of 7.5 mH, in series with a resistance of 10 Ω from 0 to 0.25s and 5 Ω from 0.25s to 0.5s.

To demonstrate the effectiveness of the proposed control method, the article will compare the voltage mode control with two other control methods: the multiple-loop controlled method using the PI and PR controller, separately. The voltage mode control, PI - multiple-loop controlled and PR - multiple-loop controlled correspond to control strategy 1, 2 and 3. The results are obtained with linear and nonlinear loads as follows:

Parameters of the control strategies.

The natural frequency of current loop	1 kHz	The cut-off frequency of DOB	1.5 kHz
The natural frequency of current loop	500 Hz	Desired phase margin (PM)	55°
The damping coefficient of current loop	1.2	The cross-over frequency (f_c)	10 kHz
The damping coefficient of voltage loop	2	The pole frequency (f_p)	30.4 kHz
Sample time of current regulator	40 µs	The zero frequency (f_z)	3.3 kHz
Sample time of voltage regulator	200 µs	The inverted zero frequency (f_L)	$f_c/10$
		The cut-off frequency LPFs	2 kHz
Sample time of DOB	40 µs	Gain (K_c)	1.8977

a. Linear load

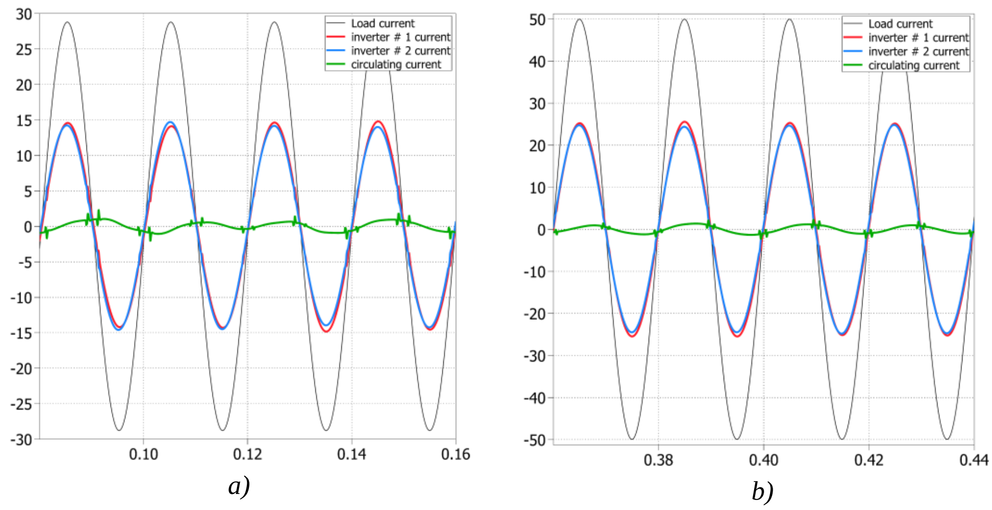


Fig. 9. Output currents of inverters, circulating current (ic = i1 - i2) and load current from a) 0.08s to 0.16s; b) 0.36 to 0.44s

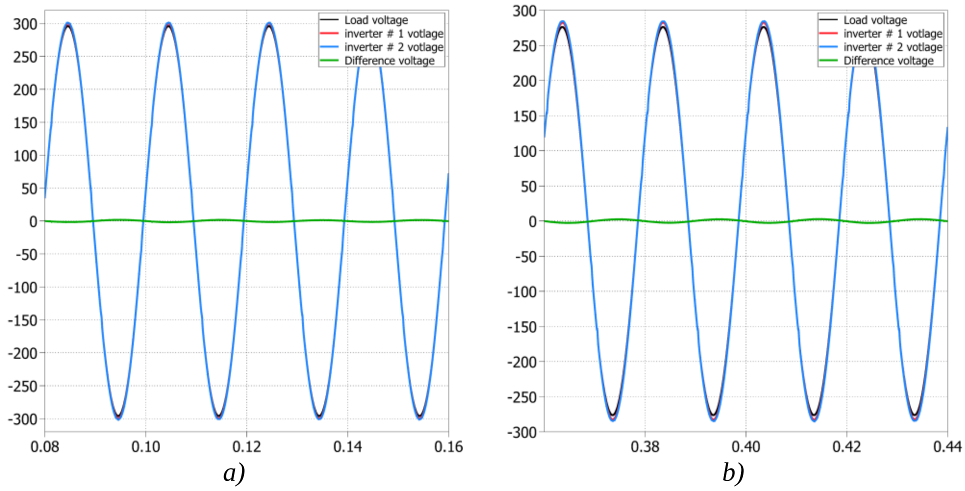


Fig. 10. Output voltage of inverters, difference voltage (vc = v1 - v2) and load voltage from a) 0.08s to 0.16s; b) 0.36s to 0.44s

Fig. 9 and Fig. 10 show the load current and the output voltage of two inverters with a linear load in cases of load changing. Fig. 11 show the active power (P) and reactive power (Q) of the system. The active power of each inverter is divided equally, however the reactive power is error. This illustrates that the line impedance difference has a significant influence on the power sharing. The graphs in Fig. 12 and Fig. 13 show the output voltage quality and the difference in current between the inverters. It can be clearly seen that the proposed method has the best output voltage when it comes to quality, the THD is smaller than others control methods. The current difference between two inverters is also minimal.

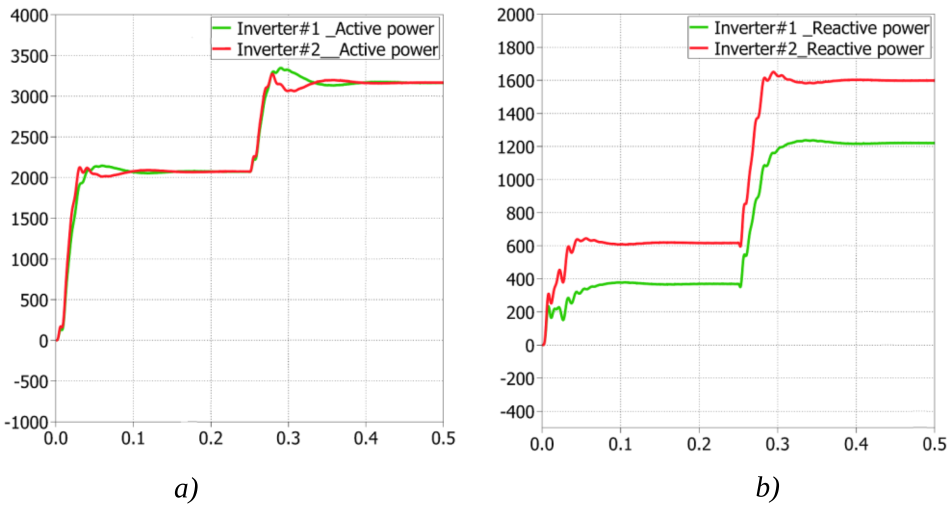


Fig. 11. (a) The active power; (b) The reactive power of inverters when supplying for a linear load.

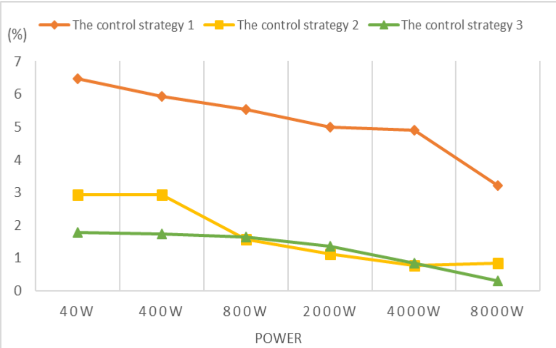


Fig. 12. Output voltage THD characteristic with linear load

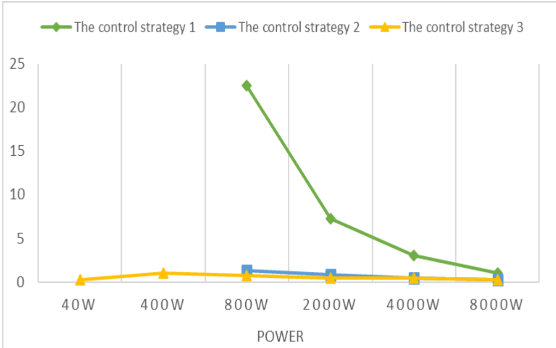
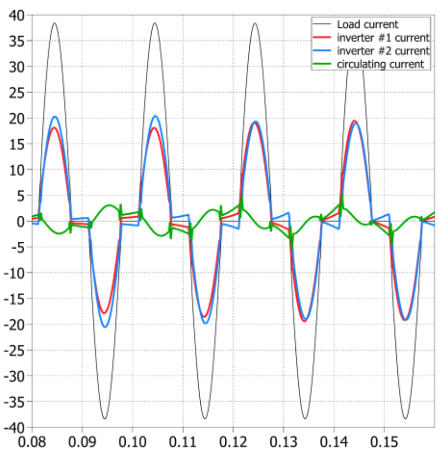


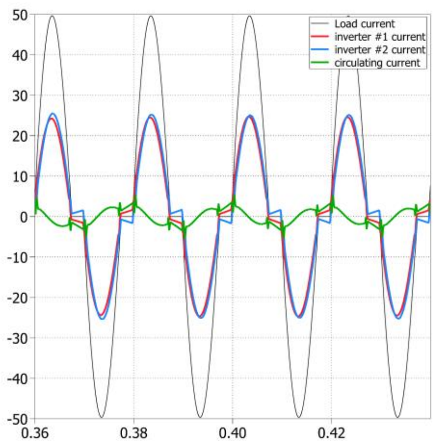
Fig. 13. Ratio peak to peak circulating current and RMS load current with linear load

b. Non-linear load

Fig. 14 and Fig. 15 illustrate the output voltage and current of 2 inverters of the system when supplying for a nonlinear load. Fig. 16 show the active power (P) and reactive power (Q) of the system. Simulation results are similar to when the inverters operate with a linear load. The results of output voltage quality and the current difference of 2 inverters are same with linear load case, in Fig. 17 and Fig. 18. The voltage mode control still has better results than the multiple-loop controlled. From that, we can see the effectiveness of the proposed control method, and the voltage mode control is simpler and has less control loop, simaltaneously.

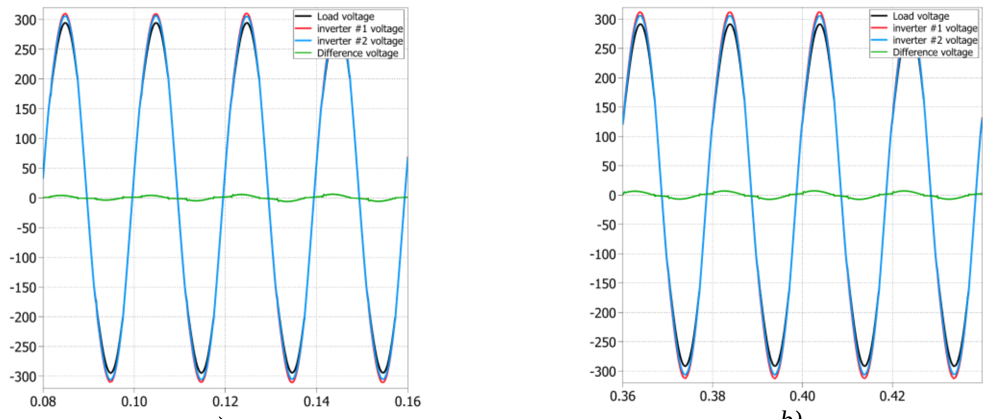


a)



b)

Fig. 14. Output currents of inverters, circulating current (ic = i1 - i2) and load current from a) 0.08s to 0.16s b) 0.36s to 0.44s



a) b)

Fig. 15. Output voltage of inverters, difference voltage (vc = v1 - v2) and load voltage from a) 0.08s to 0.16s b) 0.36s to 0.44s

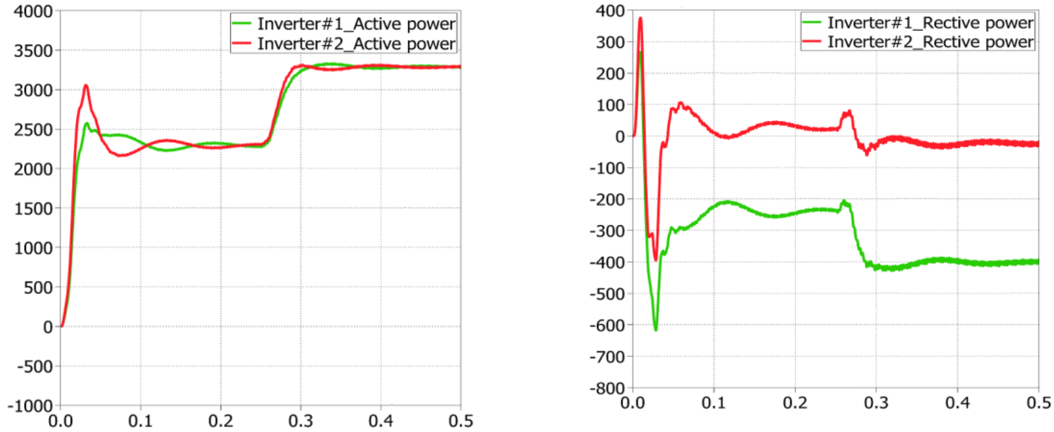


Fig. 16. (a) The active power; (b) The reactive power of inverters when supplying for a nonlinear load.

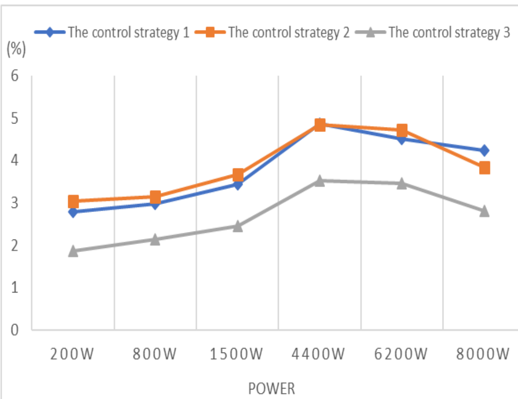


Fig. 17. Output voltage THD characteristic with non-linear load

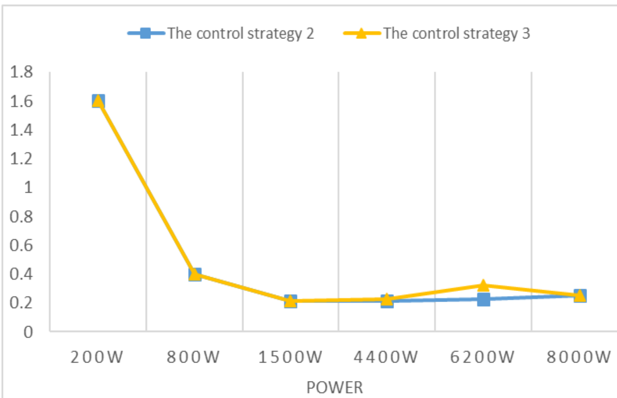


Fig. 18. Ratio peak to peak circulating current and RMS load current with non-linear load

5. Conclusion

From the simulation results, it can be concluded that the droop control algorithm using DSOGI and the proposed voltage mode control can divide the power for 2 inverters, supplying the power to the linear and nonlinear load. The accuracy of the power division is improved compared to the old methods, increasing the dynamics and stability of the system. The quality of the output voltage and the load current are better, meeting the design requirements. The proposed control structure is also simpler with only a voltage regulation loop.

References

[1] N. Hatziargyriou, H. Asano, R. Iravani, and C. Marnay, "Microgrids," *IEEE Power Energy Mag.*, Vol. 5, No. 4, pp. 78–94, Jul. 2007, doi: 10.1109/MPAE.2007.376583.

[2] H. Han, X. Hou, J. Yang, J. Wu, M. Su, and J. M. Guerrero, "Review of Power Sharing Control Strategies for Islanding Operation of AC Microgrids," *IEEE Trans. Smart Grid*, Vol. 7, No. 1, pp. 200–215, Jan. 2016, doi: 10.1109/TSG.2015.2434849.

[3] P. T. X. H. Lê Minh Phương, Lê Tấn Đại, "Giải thuật điều khiển mới chia công suất trong các bộ nghịch lưu song song khi tải phi tuyến," *Science & Techonology Development*, Vol. 18, No. K2, 2015.

[4] J. M. Guerrero, Luis Garcia de Vicuna, J. Matas, M. Castilla, and J. Miret, "Output impedance design of parallel-connected UPS inverters with wireless load-sharing control," *IEEE Trans. Ind. Electron.*, Vol. 52, No. 4, pp. 1126–1135, Aug. 2005, doi: 10.1109/TIE.2005.851634.

[5] Y. Sun, X. Hou, J. Yang, H. Han, M. Su, and J. M. Guerrero, "New Perspectives on Droop Control in AC Microgrid," *IEEE Trans. Ind. Electron.*, Vol. 64, No. 7, pp. 5741-5745, Jul. 2017, doi: 10.1109/TIE.2017.2677328.

[6] IEEE, "IEEE 1547 - 2003 Standards," *1547 TM IEEE Stand. Interconnecting Distrib. Resour. with Electr. Power Syst. Stand.*, no. July, 2003.

[7] Q. C. Zhong and T. Hornik, "Control of Power Inverters in Renewable Energy and Smart Grid Integration, " *John Wiley & Sons, 2*012.

[8] R. An, J. Liu, T. Wu, S. Wang, and B. Liu, "Analysis and design of cutoff frequency for power calculation low-pass filters in droop control," in *2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia),* Jun. 2017, pp. 1596–1600, doi: 10.1109/IFEEC.2017.7992285.

[9] J. El Mariachet, J. Matas, H. Martín, M. Li, Y. Guan, and J. M. Guerrero, "A Power Calculation Algorithm for Single-Phase Droop-Operated-Inverters Considering Linear and Nonlinear Loads HIL-Assessed," *Electronics*, Vol. 8, No. 11, 2019, doi: 10.3390/electronics8111366.

[10] J. M. Alcala, M. Castilla, L. G. de Vicuña, J. Miret, and J. C. Vasquez, "Virtual Impedance Loop for Droop-Controlled Single-Phase Parallel Inverters Using a Second-Order General-Integrator Scheme," *IEEE Trans. Power Electron.*, Vol. 25, No. 12, pp. 2993–3002, Dec. 2010, doi: 10.1109/TPEL.2010.2082003.

[11] W. Yao, M. Chen, J. Matas, J. M. Guerrero, and Z. Qian, "Design and Analysis of the Droop Control Method for Parallel Inverters Considering the Impact of the Complex Impedance on the Power Sharing," *IEEE Trans. Ind. Electron.*, Vol. 58, No. 2, pp. 576–588, Feb. 2011, doi: 10.1109/TIE.2010.2046001.

[12] S. Nagai and J. Itoh, "Open-loop-based Island-mode Voltage Control Method for Single-phase Grid-tied Inverter with Minimized LC Filter," in *2018 International Power Electronics Conference (IPEC-Niigata 2018 -ECCE Asia)*, May 2018, pp. 534–541, doi: 10.23919/IPEC.2018.8507623.

[13] R. W. Erickson and D. Maksimovic, "Fundamentals of Power Electronics, 2nd ed." *Springer*, 2001.

CHẾ ĐỘ ĐIỀU KHIỂN ĐIỆN ÁP CHO NGHỊCH LƯU MỘT PHA HOẠT ĐỘNG SONG SONG

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Tóm tắt: *Công suất tích cực và phản kháng, P và Q, là các biến quan trọng khi chia tải cho các bộ nghịch lưu kết nối song song sử dụng bộ điều khiển droop. P và Q được tính toán thông qua giá trị điện áp đầu ra bộ biến đổi và dòng điện qua tải. Tuy nhiên, khi chia công suất tải phi tuyến, các bộ lọc thông thấp với tần số cắt rất nhỏ được sử dụng để loại bỏ sóng hài của dòng điện qua tải để tăng độ chính xác khi tính P và Q. Việc này làm chậm động học của hệ thống, giảm độ tin cậy và gây ra sai lệch điều khiển. Do đó, bài báo sử dụng thuật toán DSOGI để thay thế bộ lọc thông thấp, làm tăng động học và tính ổn định của hệ thống. Thuật toán điều khiển chế độ điện áp kết hợp bộ quan sát (DOB) với cấu trúc đơn giản, đảm bảo chất lượng điện áp và dòng đầu ra nghịch lưu thỏa mãn tiêu chuẩn IEEE. Các thuật toán được kiểm nghiệm thông qua mô phỏng trên Plecs, hệ thống gồm 2 inverter 1 pha làm việc song song.*

Từ khóa: Các bộ nghịch lưu song song; droop control; trở kháng ảo; double second order generalized integrator (DSOGI).

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