International Conference on Renewable Energies and Power Quality (ICREPQ'18)

Salamanca (Spain), 21th to 23th March, 2018

Renewable Energy and Power Quality Journal (RE&PQJ)

ISSN 2172-038 X, No.16 April 2018

Power Calculation Algorithm for Single-Phase Droop-Operated Inverters Considering Nonlinear Loads

J. El Mariachet*, J. Matas†**, Helena Martín†, Abdullah Abusorrah**

* Department of Electronic Engineering, Universidad Politécnica de Cataluña (UPC), Barcelona, Spain.

† Department of Electric Engineering, Universidad Politécnica de Cataluña (UPC), Barcelona, Spain.

**Renewable Energy Research group, King Abdulaziz University (KAU), Jeddah, Saudi Arabia.

Abstract—**The average active and reactive powers, P_{av} and Q_{av}, are crucial parameters that have to be calculated when sharing common loads between parallelized droop-operated single-phase inverters. However, low-pass filters (LPF) with very low cut-off frequency should be used to minimize the distortion impact in the amplitude and frequency references provided by the droop equations. This forces the control to operate at a very low dynamic velocity, degrading the stability of the parallelized system. For this reason, different solutions had been proposed to increase the droop operation velocity in literature, but with the consideration of only sharing linear loads. The issues derived from the sharing of nonlinear loads had not been properly considered. This paper proposes a method to calculate P_{av} and Q_{av} using second order generalized integrators (SOGI) that increase the velocity of the droop control algorithm considering nonlinear loads as the design worst case scenario. Then it is employed a double SOGI (DSOGI) approach to filter the current non-sinusoidal waveform and provide the fundamental component, which results in a faster transient response and improves the system's stability. The proposed calculation method shows to be faster than other approaches when considering nonlinear loads. Simulations are provided to validate the proposal.**

Keywords-component; Active and reactive power calculation, single-phase inverters, nonlinear loads, inverter parallelization, droop method, trade-off speed and accuracy.

I. INTRODUCTION

The calculation of the averaged active, P_{av}, and reactive, Q_{av}, powers is an important aspect in the droop based local control algorithm used to parallel single-phase inverters without intercommunication, since it has a critical influence on the transient response speed of the inverter and in the system stability [1]-[3]. The calculation of P_{av} and Q_{av} had been usually performed by the multiplications of the inverter delivered output current, i_o, with the inverter output voltage, v_o, and with its $\pi/2$ phase shifted version, $v_{o\perp}$, for obtaining the active and reactive instantaneous powers, p_i and q_i, respectively. A LPF should be applied to achieve the averaged values of p_i and q_i and for removing the double frequency component resulting for the multiplication of these sinusoidal signals [4], [5] and [6]-[12]. In this operation, $v_{o\perp}$ can be obtained by different approaches such as a transport delay (TD) in [13] and [14], an extended three-phase *dq* SRF approach applied to single-phase systems in [15] and [16], and a method using the quadrature output of a SOGI filter in [17]. In [18] a method based on SOGI for calculation of powers and later cancelling the double frequency component similarly to [6] had been proposed. Although the calculation time was reduced in one order of magnitude against linear loads, this method employed also a LPF for obtaining P_{av} and Q_{av}, which slows down the transient response. Moreover, a proposal based on a discrete Fourier transform (DFT) was presented in [19] for extracting averaged values, but it introduced a severe delay that makes it unsuitable when abrupt changes of load occur. For this reason, in [20] a method was presented for calculating the active and reactive powers through optimizing a cost function of P and Q by means of LMS adaptive algorithm. However, approximations achieved in the P and Q expressions are only possible in steady state and against linear loads.

In general, all these proposals have in common the objective of trying to enhance somehow the droop-operated system stability by means of achieving a fast and accurate calculation of the averaged powers for the droop references. However, the validity of these approaches is only partial when sharing nonlinear loads.

This paper proposes a modification in the power evaluation scheme proposed in [6] and [18], using a DSOGI approach for obtaining the fundamental component of the inverter output current, i_{oF}, which is used in the power calculation against a RC rectified nonlinear load with a 215% total harmonic distortion (THD). The filtering capability of the DSOGI is determined by its damping factor parameter, ξ, that will be designed for keeping the ripple in the calculated powers below a predefined desired value. The use of the DSOGI allows the removing of the LPF from the initial calculation scheme and reduces the time for obtaining the averaged powers. This

DSOGI structure must be designed with a proper value of ξ for giving a lower settling time during transients. The proposal is then compared with the classical droop approach and with [6] and [18] under the assumption of causing the same amplitude ripple at the obtained powers for a given RC rectified nonlinear load. The obtained responses show to be faster when abrupt load changes occur and determine to which point the speed and stability of the system can be enhanced.

In Section II the calculation block in a droop based local control structure is contextualized and described, for a single-phase inverter. In Section III, an advanced method for calculating P-Q based on [18] is shown. Section IV proposes the novel calculation of active and reactive powers based on a DSOGI filter approach and also shows the simulation results for validating the proposal.

II. POWER CALCULATION IN SINGLE-PHASE DROOP-OPERATED INVERTERS

This section deals with the power calculation of a single-phase inverter when sharing a common load with another parallelized inverter using the droop method. This section and the rest of the paper is focused on the power calculation dynamics of one of the inverters in attempt to view the problems when sharing a nonlinear load, to propose a solution to deal with the distorted currents, and to see the relationship between the transient speed and the filtering capability of the power calculation, which will improve the stability of the system and the accuracy of power sharing.

Fig. 1 represents a basic scheme of a single-phase inverter that is operated with the droop method. In this figure it can be seen that the control scheme is composed by a P-Q power calculation block, a droop method block, and inverter's control inner loops plus pulse width modulation block (PWM). The P-Q block uses the inverter's output voltage and current, v_o and i_o, to deliver the averaged powers, P_{av} and Q_{av}, to the droop block that uses them to generate the inverter's reference voltage, v_{ref}, to command the inverter power switches through the inner loops plus PWM control block.

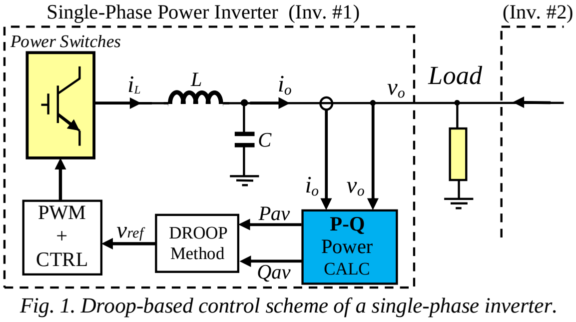


Fig. 1. Droop-based control scheme of a single-phase inverter.

Fig. 2 shows the traditional power calculation that obtains the averaged powers, after the multiplications between voltages and current to produce an instantaneous active, *pi*, and reactive, *qi*, powers. Then, LPFs are used to obtain the respective averaged powers [17].

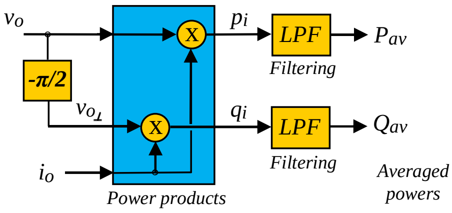


Fig. 2 Block diagram of conventional P-Q power calculation providing averaged powers.

The droop control method determines the operating frequency and amplitude voltage of the inverter through the following equations, when line impedance and output inverter's impedance are considered to be mainly inductive:

$$\omega^* = \omega_n - m \cdot P_{av} \quad (1)$$

$$V^* = V_n - n \cdot Q_{av} \quad (2)$$

where m and n are the droop coefficients, ω_n and V_n are the nominal frequency and amplitude and ω^* and V^* are the provided frequency and amplitude references. These references are used to generate the following sinusoidal voltage reference for the inverter's inner control loops to follow.

$$v_{ref} = V^* sin(\omega^* t) \quad (3)$$

Assuming that the output voltage and current of the inverter are [15]

$$v_o(t) = V \cdot sin(\omega_0 t) \quad (4)$$

$$i_o(t) = I \cdot sin(\omega_0 t - \varphi_o) \quad (5)$$

where V and I are the voltage and current amplitudes, ω_o is the fundamental frequency and φ_o is the phase angle between v_o and i_o. The quadrature voltage, with a $\pi/2$ delay, is defined as

$$v_{o\perp}(t) = V \cdot \sin(\omega_o t - \tfrac{\pi}{2}) \quad (6)$$

So, the instantaneous active and reactive powers could be formulated as

$$p_i = v_o(t) \cdot i_o(t) = \frac{VI}{2} \cdot [cos\varphi_o - cos(2\omega_0 t - \varphi_o)] = \\ = P_{av} + \tilde{p} \quad (7)$$

And, in a similar way,

$$q_i = v_{o\perp}(t) \cdot i_o(t) = \frac{VI}{2} \cdot [sin\varphi_o - sin(2\omega_0 t - \varphi_o)] = \\ = Q_{av} + \tilde{q} \quad (8)$$

where P_{av} and Q_{av} are the average active and reactive powers and $\tilde{p}$ and $\tilde{q}$ are the oscillating components at twice of the fundamental operating frequency provided by the droop method.

The LPFs used to filter these instantaneous powers, see Fig. 2, should have a low cut-off frequency value, *fc*, in order to filter properly the double frequency components, $\tilde{p}$ and $\tilde{q}$. This value is typically of one or two order of magnitude lower than the inverter's operating frequency [21], [22]. The *fc* value finally determines the speed of the droop method, which is too slow. Moreover, *fc* should be reduced more to be able to handle the sharing of nonlinear loads. Also, nonlinear loads may introduce strong distortions in the inverter current, [23], which are directly conveyed to the instantaneous powers. Therefore, calculation of powers become much more complex and not only the double frequency power components shall be removed. In single phase parallelized inverters the main concern when sharing nonlinear loads is to avoid the excessive power ripple induced by these loads. The power ripples cause strong distorting swings in the provided droop frequency and amplitude references, ω^* and V^*, which, in turn, cause distortion in inverter's voltage reference, v_{ref}, and provokes a bad droop operation of the system. In fact, the value of fc should be designed to be typically less than 1Hz in order to avoid the impact of nonlinear loads.

III. ADVANCED P-Q POWER CALCULATION METHOD

A SOGI is a special linear filter with one input, v_{in}, and two outputs, v_d and v_q, one in-phase and the other $\pi/2$ delayed with respect to the input, respectively. These outputs have the following band-pass filter (BPF) and LPF transfer functions relationships regarding to the input

$$H_d(s) = \frac{v_d(s)}{v_{in}(s)} = \frac{2\xi_i\omega_i^2 \cdot s}{s^2 + 2\xi_i\omega_i \cdot s + \omega_i^2} \quad (9)$$

$$H_q(s) = \frac{v_q(s)}{v_{in}(s)} = \frac{2\xi_i\omega_i^2}{s^2 + 2\xi_i\omega_i \cdot s + \omega_i^2} \quad (10)$$

where ξ_i is the filter damping factor and ω_i its tuning center frequency. These two parameters determine the settling time of the transient response of this filter, which is

$$t_s \approx \frac{4}{\xi_i\omega_i} \quad (11)$$

Fig. 3 shows the proposed P-Q calculation method in [18] for accelerating the calculation of the active and reactive powers.

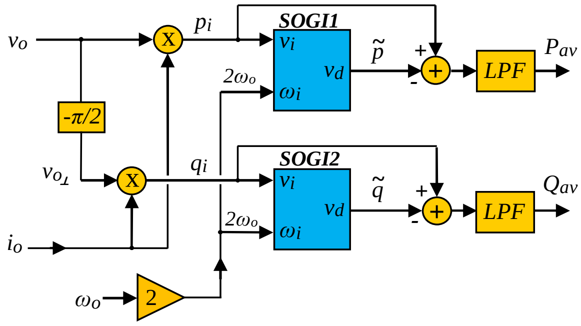


Fig. 3. P-Q calculation block scheme based on [18].

The SOGI1 and SOGI2 in Fig. 3 are used for extracting the pulsating double frequency power components, $\tilde{p}$ and $\tilde{q}$, respectively. These SOGI are tuned both at $2\omega_o$ and $\xi_1=\xi_2=1$. The LPFs are used for a better filtering and provide the averaged powers P_{av}.and Q_{av}. Fig. 3 do not show the method for generating the $-\pi/2$ delay since it is not mentioned in [18]. Therefore another SOGI, SOGI0, tuned at ω_o and $\xi=0.707$, is used for generating this delay as shown in Fig. 4, for avoiding delay issues reported in [13], [14], [19] .

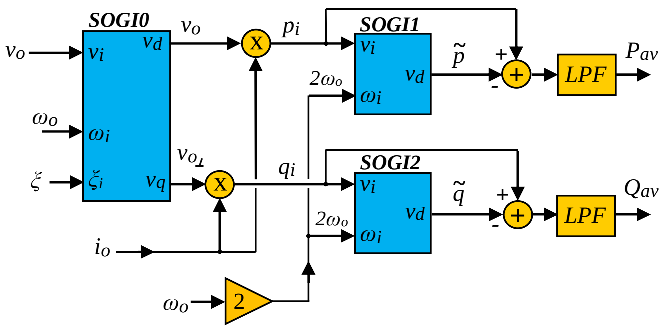


Fig. 4. P-Q calculation block scheme of Fig. 3 using an additional SOGI for generating the -π/2 delay.

Fig. 5 shows the simulations results after using the P-Q scheme of Fig. 4 when sharing a linear load that produces a current perturbation from 4A to 8A at time 1s.

For sake of simplicity Fig. 5 only shows the active power, P_{av}. The dynamics are compared with the obtained by the conventional droop method depicted in Fig. 2, named as P_{droop}, using a LPF with fc=1Hz. The P_{av} power of Fig. 4 is named as P_{adv} to differentiate it, from now on, from the other methods. The cut-off frequency for the advanced power calculator LPF was designed to be 10Hz.

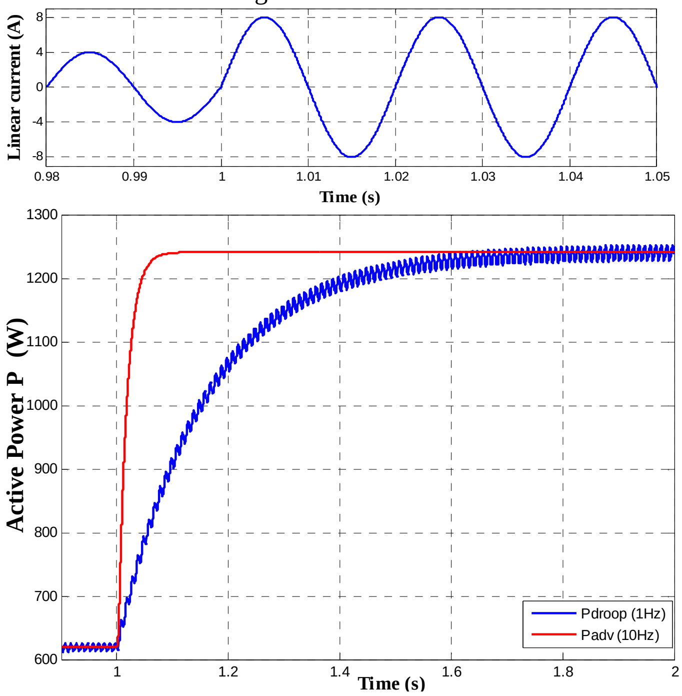


Fig. 5. P_{droop} and P_{adv} transient response for a linear load current perturbation from 4A to 8A at 1s: up) Detail of the perturbation; down) P_{droop} and P_{adv} calculated powers.

As shown in Fig. 5, the P_{adv} dynamics remove the double frequency component and is much faster than the P_{droop}, which still contains a small double frequency component. These results are compatible with those reported in [18]. However, the perfect dynamic behavior depicted in Fig. 5 vanishes when a nonlinear load that induces distortion in current is shared.

Fig. 6 shows the dynamics of the system when a nonlinear load is used. In this case, the load is a rectifier supplying a RC load that draws a highly distorted current with 4A peak and that suffers a perturbation that pushes the peak to 8A. The simulation parameters are shown in Table I.

TABLE I. SIMULATION PARAMETERS FOR FIG. 4.

V_n	311V
ω_n	2π50(rad/s)
R at t <1s; R at t >1s	1100Ω;372 Ω
C	470μF
Current THD	215%
ξ_1	0.7
ξ_2,ξ_3	1
fc_{droop}; fc_{adv}	1Hz; 10Hz

As shown in Fig. 6, the dynamics of the proposed method in [18] were never considered using a nonlinear load, similarly to other proposals mentioned in Section I. Thus, in the presence of nonlinear loads the method has excessive steady state ripple that corrupts the calculated powers, oppositely to the stated in [18]. Fortunately, the filtering capabilities of the LPF in Fig. 4 can be improved by reducing *fc* to 2.2Hz. Therefore, the ripple of P_{adv} is diminished until the same level than the produced by the conventional droop method. Fig. 7 shows this situation and also shows how the advanced method is still faster calculating P_{adv} than the conventional droop controller. Note that both methods have been compared under the same dynamical and distortion-attenuation conditions, being better the advanced one but with less effectivity than initially argued.

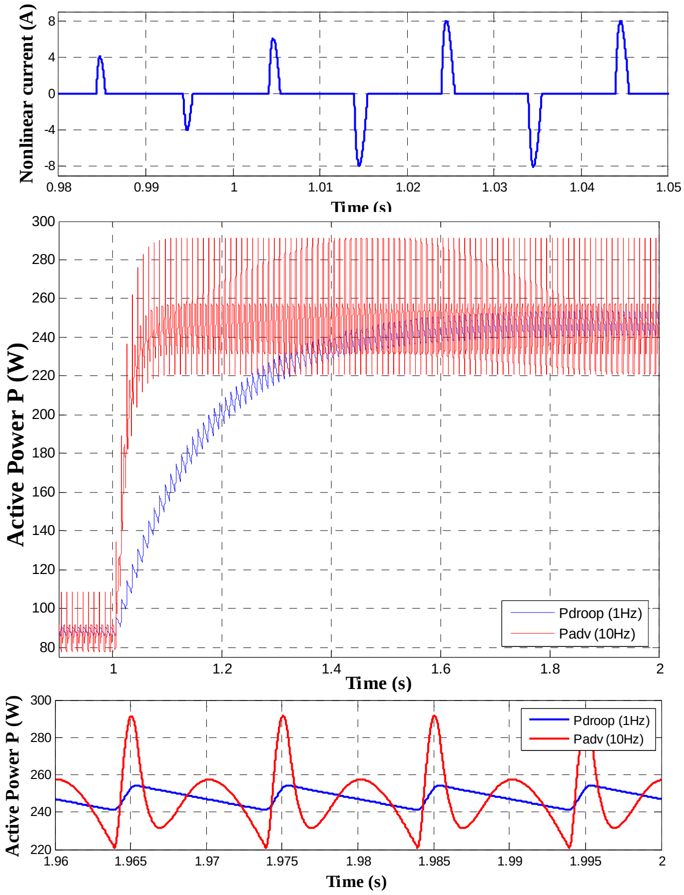
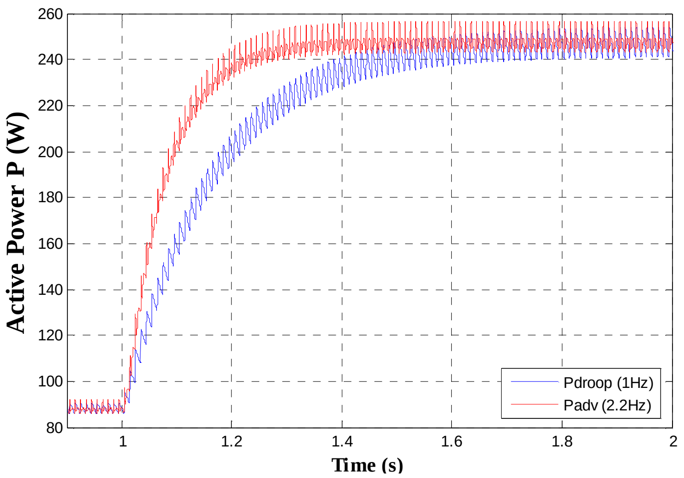


Fig. 6. P_{droop} and P_{adv} transient response for a nonlinear rectifier-type load perturbation in current from 4A peak to 8A peak at 1s: up) Detail of the distorted load current perturbation from 4A peak to 8A peak; middle) P_{droop} and P_{adv} calculated powers; down) Detail of the calculated powers showing their ripple.



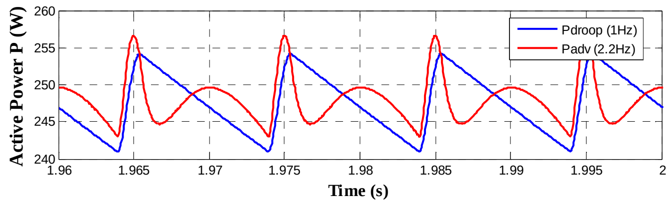


Fig. 7. P_{droop} and P_{adv} transient response for a nonlinear rectifier-type load perturbation from 4A peak to 8A peak at 1s: up) P_{droop} and P_{adv} calculated powers, for P_{adv} with a LPF with fc=2.2Hz; down) Detail of the calculated powers showing their ripple.

Note also that there is a positive offset in the calculated active power at steady state, since the mean value of P_{adv} is slightly higher than this of P_{droop}, see lower plot of Fig. 7.

IV. Proposed P-Q DSOGI power calculation Method

Fig. 8 shows the proposed power calculation method that consists in a modification of Fig. 4 to enhance the dynamical response when sharing nonlinear loads.

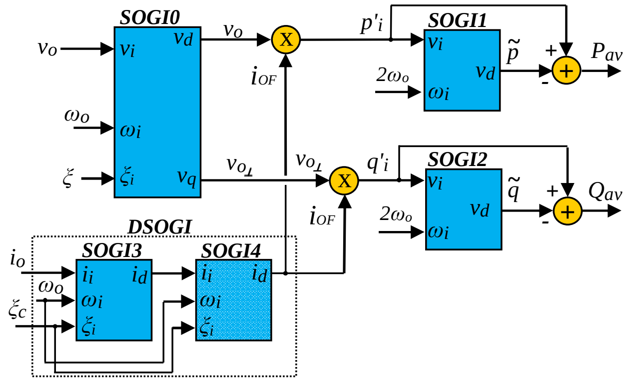


Fig. 8. Proposed P-Q calculation method for dealing with nonlinear loads and using a DSOGI approach.

When the proposed nonlinear load is connected, the output current of the inverter can be expressed as [23]:

$$i_{o(t)} = I_{DC} + I_0 \cdot sin(\omega_o t + \varphi_o) + \sum_{h=2}^{N} I_h \cdot sin(h \cdot \omega_o t + \varphi_h) \qquad (12)$$

where the sub index ***h*** represents the harmonic number, ***N*** the maximum set of harmonics, I_{DC} the DC component, I_o and I_h are the amplitudes of the fundamental and harmonic components, respectively. The fundamental frequency is ω_o and $h \cdot \omega_o$ represents its harmonic multiples. Finally, φ_o and φ_h are the phase-shift of the fundamental and of each harmonic component, respectively. Then, the instantaneous powers should be redefined as:

$$p_i' = P_{av} + \tilde{p} + v_{o(t)} \cdot \sum_{h=2}^{N} I_h \cdot sin\left(h \cdot \omega_o t + \varphi_h\right) \qquad (13)$$

$$q_i' = Q_{av} + \tilde{q} + v_{o\perp(t)} \cdot \sum_{h=2}^{N} I_h \cdot sin\left(h \cdot \omega_o t + \varphi_h\right) \qquad (14)$$

Consequently (13) and (14) contain the DC, double frequency and higher harmonic order components of the powers and the subtraction of only the double frequency component is not enough for the proper calculation of P_{av} and Q_{av}. Then, it becomes necessary the filtering of the measured current, i_o, in order to reject its harmonics components previously for resulting in a simpler and faster calculation of powers as in (7) and (8). For this purpose, in Fig. 8, the DSOGI, formed by SOGI3 & 4, is used to filter the non-sinusoidal output current and to provide its fundamental component. Then, it is obtained the product with the in-phase and the quadrature voltages and generate instantaneous powers with only the double frequency components and without third or higher order harmonics. Later, SOGI1 and SOGI2 are used for only removing the double frequency components with the help of the subtracting blocks. The resulting value is named as P_{DSOGI} for the active power, and Q_{DSOGI} for the reactive one. In Fig. 8, the DSOGI BPF filtering action is so strong that allows to remove the LPF from the scheme, which accelerates further the P-Q dynamic response. Also, the subharmonic components of current are rejected due to the BPF behavior of the SOGI filter. In this case, because the DSOGI is used in the current, the transient response speed is determined by (11) and it relays mainly in ξc, since the frequency provided by the droop method, ω^*, varies in a small range around the nominal ω_n. Therefore, the DSOGI damping factor is tuned to filter the non-sinusoidal current to a point in which the produced power ripple is identical in amplitude as the conventional droop controller. In this case, this is achieved for $\xi c=\xi_3=\xi_4=0.21$. Fig. 9 shows the simulation results, which yield that the proposed method is faster calculating the active power and achieves a lower steady state ripple.

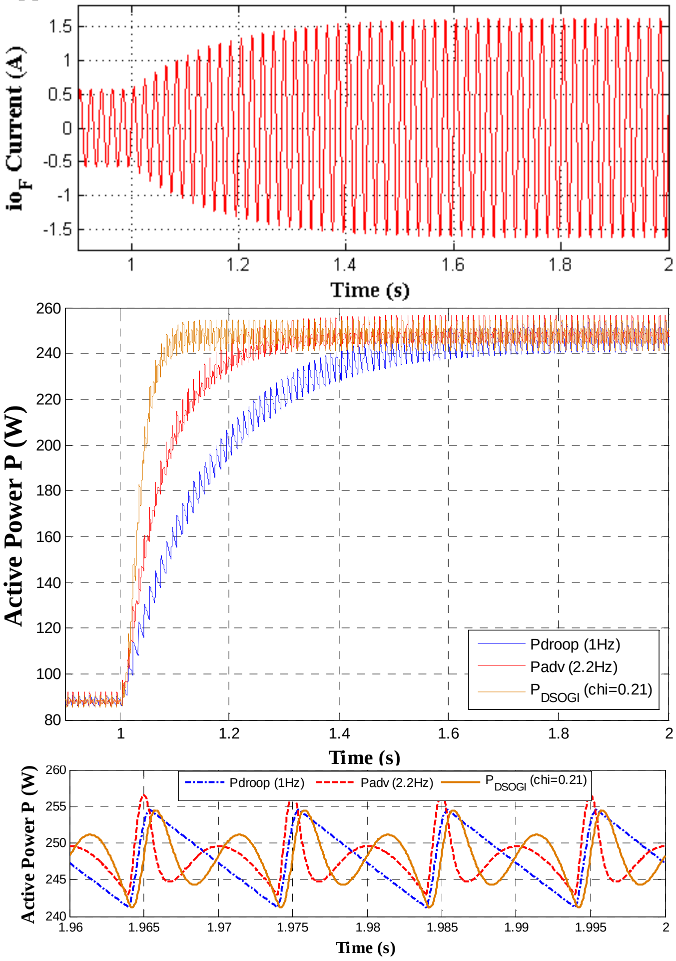


Fig. 9. Active power transient responses for a nonlinear rectifier-type load perturbation from 4A peak to 8A peak at 1s: up) Fundamental current i_{oF} provided by the DSOGI filter; middle) P_{DSOGI} , Padv and Pdroop calculated powers; down) Detail of calculated powers at steady-state.

Note that the calculated P_{DSOGI} power has not positive offset error in steady state in contradistinction with P_{adv}. This means that the proposed method is also more accurate than proposed in [18]. Table II yields the measured rise time for the transient responses depicted in Fig. 9, which shows that the proposed method implies a 60.00% and a 79.69% reduction in the rise time regarding P_{adv} and P_{droop}, respectively.

TABLE II. RISE TIME MEASUREMENTS FROM FIG. 9.

Measurements	
P_{droop}	325ms
P_{adv}	165ms
P_{DSOGI}	66ms
Improvements	
Improvement P_{DSOGI} ***vs*** P_{adv}	60.00%
Improvement P_{DSOGI} ***vs*** P_{droop}	79.69%

V. CONCLUSIONS

In this work a P-Q calculation method has been proposed for single-phase parallelized inverters with the purpose of improving the speed and accuracy of the power calculation when they are sharing nonlinear loads. The dynamic response of the power calculation used in the conventional droop method and in another advanced method is analyzed first to show their limitations in speed and accuracy when sharing a RC-rectified type nonlinear load. For this reason a novel calculation method has been proposed and compared with the previous ones. The simulations results, under the same distorting conditions in current, show how the proposed method obtains the P-Q powers at a 76.69% faster than the proposed one for the conventional droop controller. Also it obtains also the P-Q powers at a 60.00% faster than the advanced one based on [18]. This improvement supposes an enhancement in the droop speed operation under non-sinusoidal conditions in current that may lead to a better dynamic performance of non-hierarchically controlled inverters in microgrids. Further works will be carried out to determine the improvements in load sharing dynamics for the paralleled systems and in its stability.

REFERENCES

[1] E. A. A. Coelho, P. C. Cortizo and P. F. D. Garcia, "Small signal stability for single phase inverter connected to stiff AC system," *Conf. Record of the 1999 IEEE Industry Applications Conf. 32th IAS Annual Meeting (Cat. No.99CH36370)*, pp. 2180-2187 vol.4, 1999.

[2] M. Soshinskaya, W. H. J. Graus, J. M. Guerrero, J. C. Vasquez, "Microgrids: experiences barriers and success factors", *Renew. Sustain. Energy Rev.*, vol. 40, pp. 659-672, 2014.

[3] L. S. Araújo, D. I. Narváez, T. G. Siqueira and M. G. Villalva, "Modified droop control for low voltage single phase isolated microgrids," *2016 IEEE Int. Conf. on Automatica (ICA-ACCA)*, pp. 1-6, 2016.

[4] "IEEE Standard definitions for the measurement of electric power quantities under sinusoidal, nonsinusoidal, balanced or unbalanced conditions, IEEE Standard 1459-2010", Mar. 2010.

[5] J. Lu, Y. Wen, Yingchao Zhang and W. Wen, "A novel power calculation method based on second order general integrator," *2016 IEEE 8th Int. Power Electronics and Motion Control Conf. (IPEMC-ECCE Asia)*, Hefei, pp. 1975-1979, 2016.

[6] E. T. Andrade, P. E. M. J. Ribeiro, J. O. P. Pinto, C. L. Chen, J. S. Lai and N. Kees, "A novel power calculation method for droop-control microgrid systems," 2012 27th Annual IEEE Applied Power Electronics Conf. and Exp., (APEC), pp. 2254-2258., 2012.

[7] Z. Ren, M. Gao, Q. Mo, K. Liu, W. Yao, M. Chen and Z. Qian "Power Calculation Method Used in Wireless Parallel Inverters Under Nonlinear Load Conditions," in Proc. of APEC, pp. 1674-1677, 2010.

[8] E.C. Furtado, L.A. Aguirre and L.A.B. Torres, "UPS Parallel Balanced Operation Without Explicit Estimation of Reactive Power - A Simpler Scheme," IEEE Trans. on Circuits and Systems II: Express Briefs, vol.55, no.10, pp. 1061-1065, Oct. 2008.

[9] J.M. Guerrero, J. Matas, L. G. Vicuna; M. Castilla and J. Miret, "Decentralized Control for Parallel Operation of Distributed Generation

Inverters Using Resistive Output Impedance," IEEE Trans. on Industrial Electronics, vol.54, no.2, pp. 994-1004, Apr. 2007.
[10] S. A. O. Silva, R. Novochadlo and R.A. Modesto, “Single-phase PLL structure using modified p-q theory for utility connected systems,” in Proc. of IEEE PESC, pp. 4706-4711, 2008.
[11] H. Wang, X. Yue, X. Pei and Y. Kang, “A new method of power calculation based on parallel inverters,” in Proc. of IEEE EPE-PEMC, pp. 1573-1576, 2009.
[12] Yu, D. Xu and K. Ma, “A Novel Accurate Active and Reactive Power Calculation Method for Paralleled UPS System,” in Proc. of APEC, pp. 1269–1275, 2009.
[13] Zheng Ren; Mingzhi Gao; Qiong Mo; Kun Liu; Wei Yao; Min Chen; Zhaomin Qian, "Power calculation method used in wireless parallel inverters under nonlinear load conditions," Applied Power Electronics Conf. and Exp., (APEC), 2010 25th Annual IEEE, pp.1674,1677, 21-25 Feb. 2010.
[14] Wei Yu; Dehong Xu; Kuian Ma, "A Novel Accurate Active and Reactive Power Calculation Method for Paralleled UPS System," Applied Power Electronics Conf. and Exp., 2009. (APEC 2009). 24th Annual IEEE, pp.1269,1275, 15-19 Feb. 2009
[15] H. Akagi, E.H. Watanabe, M. Aredes, "Instantaneous Power Theory and Application to Power Conditioning," Piscataway, NJ: John Wiley & Sons, Inc., 2007, pp. 5-28
[16] Mingzhi Gao; Shangda Yang; Cheng Jin; Zheng Ren; Min Chen; Zhaoming Qian, "Analysis and experimental validation for power calculation based on p-q theory in single-phase wireless-parallel inverters,"Applied Power Electronics Conference and Exposition (APEC), 2011 26th Annual IEEE, pp.620,624, 6-11 March 2011
[17] J. Matas, M. Castilla, L. G. d. Vicuña, J. Miret and J. C. Vasquez, "Virtual Impedance Loop for Droop-Controlled Single-Phase Parallel Inverters Using a Second-Order General-Integrator Scheme," in *IEEE Trans. on Power Electronics*, vol. 25, no. 12, pp. 2993-3002, Dec. 2010.
[18] S. Tolani and P. Sensarma, "An improved droop controller for parallel operation of single-phase inverters using R-C output impedance," *2012 IEEE Int. Conf. on Power Electronics, Drives and Energy Systems (PEDES)*, Bengaluru, 2012, pp. 1-6.
[19] Y. Yang, F. Blaabjerg and H. Wang, "Low voltage ride-through of single-phase transformerless photovoltaic inverters," *2013 IEEE Energy Conversion Congress and Exposition*, Denver, CO, 2013, pp. 4762-4769.
[20] Y. Yang and F. Blaabjerg, "A new power calculation method for single-phase grid-connected systems," *2013 IEEE International Symposium on Industrial Electronics*, Taipei, Taiwan, 2013, pp. 1-6.
[21] J. M. Guerrero, N. Berbel, J. Matas, L. G. de Vicuna and J. Miret, "Decentralized Control for Parallel Operation of Distributed Generation Inverters in Microgrids Using Resistive Output Impedance," *IECON 2006 - 32nd Annual Conference on IEEE Industrial Electronics*, Paris, 2006, pp. 5149-5154.
[22] H. Song and K. Nam, “Dual current control scheme for PWM converter under unbalanced input voltage conditions,” IEEE Trans. Ind. Electron., vol. 46, no. 5, pp. 953-959, Oct. 1991.
[23] IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions - Redline," in IEEE Std 1459-2010 (Revision of IEEE Std 1459-2000) - Redline , vol., no., pp.1-52, March 19 2010
.