Fast Real and Reactive Power Flow Control of Grid-Tie Photovoltaic Inverter

R. Sadnan,[1*] and Md. Ziaur Rahman Khan [1]

[1]Dept. of EEE, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh
[*] rabayet.sadnan@gmail.com

Abstract— **A fast power flow control algorithm for a grid tie Photovoltaic inverter is presented here. The proposed method has the merits of design simplicity. The algorithm is fast and has the virtue of quick response to the change of required power output for the PV inverter. Current mode asynchronous sigma delta modulation is implemented to ease the controlled sensitivity to the grid current distortion. This process also opens a window to reduce the harmonics in the current. The simulation is performed in MATLAB/Simulink. A comparison is provided to observe the response behaviour of the algorithm.**

Index Terms—**Photovoltaic inverter, reactive power control, real power, grid-tied inverter, Current mode asynchronous sigma delta modulation, ac main cycle.**

I. INTRODUCTION

Photovoltaic (PV) power generation is an epitome of green renewable energy source. Chief impetus for wandering different aspects of PV generators is the forecasted dearth of fossil fuel. Because of the high cost of the batteries, the most efficient approach is to use grid-tied PV system without the energy storage facilities [1] instead of isolated PV system. Grid-tied PV systems need to supply reactive power as well as real power to the grid, which is very important for the stability of a power system. This feature of the PV system plays important role to instigate more exploration of controlling power injection [2], [3].

Due to the PV system's imperative nature, different control strategies for regulation of reactive and active power has been developed for grid tied inverter [4], [5]. Maknouninejad proposed a new control scheme that enables inverter of the PV system to absorb a little active power from the grid, regulate its DC bus voltage within limits, and inject the desired level of reactive power, even when the PV power is unavailable [4]. This control scheme enables us to operate only in VAR mode. A new theory of instantaneous power in single phase circuits which operate in transient states, is presented in [5]. The theory is based on Hilbert transform. In [6], Bojoi implemented a sinusoidal signal integrator along with the p-q theory to reduce the controlled sensitivity to the grid voltage distortion. Phase locked loop (PLL) for adjusting injected power is proposed by Q. Zhang in [7]. Discrete Fourier transform PLL is used by Liu in [8], to reach more precise reactive power control.

Robust pole placement technique, determined using the linear matrix inequality with D-stability criteria, is used to design the controller by Sampaio [9]. These methods require a powerful processor or software platform to process, as these methods encompasses complex mathematical expression and more intricate steps.

Sun and Liu in [10], [11] proposed a simplified method for controlling the output power of the inverter. The reference current is controlled here and the method is scalar in nature. This scalar current reference generation (CRG) is much easier than the previously used methods [12]. Though it lowers the computational burden compared to the previous practises, many complicated functions are still required, which limits the burden too.

For further reduction of computational burden, Chang [12] proposed an effective output power calculation method using only two sampled current value within one ac mains cycle. The method can commendably measure the injected active and reactive power. It uses iterative method to generate reference current for the inverter pulse generators. Though this method is simpler in nature, but the iteration process makes the convergence time consuming.

Here a new fast and effective algorithm for CRG block is proposed. To ease the controlled sensitivity to the grid current distortion, current mode asynchronous sigma-delta modulation (CMASDM) is adopted for the PV inverter's output current control strategy [13].

In this paper, the methodology is outlined and the proposed algorithm is provided in section II. In section III, the simulated results and the comparisons with the available literatures is provided. The observations from the results are described and concluding remarks are drawn in section IV.

II. METHODOLOGY

The proposed controller model consists of the simplified output power calculation, power adjustment block - which uses the new fast algorithm. These first two blocks generate the necessary reference for the output current of inverter. Finally, the last block of the model is CMASDM described as in [13]. This block receives the reference current, generated from the previous block. And this CMASDM block then produces required gate pulses for the switches of the inverter.

A. Output Power calculation

The output power of inverter can be calculated very easily. Two current samples at two selected points within one ac cycle can be very handful to measure both supplied power and var. The grid voltage is assumed to be purely sinusoidal for this method, so that the output power can be directly measured by injected sinusoidal current [12].

The active output power of the inverter can be determined or calculated as

$$P_{out} = \frac{1}{2} V_m I_m \cos\theta = \frac{1}{2} V_m i_{ac}(t_p) \tag{1}$$

Similarly, the reactive output power (var) of the inverter can be determined as:

$$Q_{out} = \frac{1}{2} V_m I_m \sin\theta = \frac{1}{2} V_m i_{ac}(t_q) \tag{2}$$

978-1-5090-2963-1/16/$31.00 ©2016 IEEE

Where,

$v_{ac}(t) = V_m \sin(\omega t)$

$i_{ac}(t) = I_m \sin(\omega t - \theta)$

t_p = Time when the voltage is maximum.

t_q = Time when the voltage is crossing zero.

So, from above equation (1) and (2), the active and reactive power of the inverter can be calculated by two sampled current values. This method reduces tremendous amount of calculative load for the processor. And is very simple way to calculate injected active and reactive power.

B. Power adjustment block

In [12], the author, et al. proposed an iterative method to adjust the required power. The conceptual diagram is given below in fig. 1.

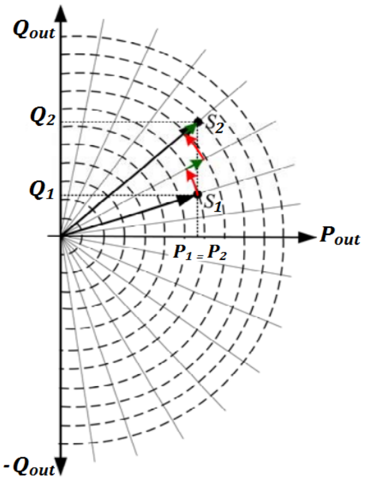

Fig. 1 Conceptual diagram for operating point of PV inverter

To move from point S1 to S2, number of steps are needed in the iterative method. It can be easily seen from the above figure. So the time required for power adjustment is high. A new method is proposed in this paper. The method is to move from point one operating point to another directly, instead of by small steps and adjustments. Here, for S2 point,

$$\theta_{new} = tan^{-1}\left(\frac{P_{REF}}{Q_{REF}}\right) \qquad (3)$$

And, let the change in magnitude of the current due to the change in operating point is ΔI_m

$$\Delta I_m = \frac{2P_{REF}}{V_m}\left[\frac{1}{cos\theta\, cos\Delta\theta - sin\theta\, sin\Delta\theta} - \frac{1}{cos\theta}\right] \qquad (4)$$

Where,

P_{REF} = Reference active power

Q_{REF} = Reference reactive power

θ_{new} = Phase angle of current for P_{REF} and Q_{REF}

θ = Initial phase angle of current

$\Delta\theta = \theta_{new} - \theta$

So, the new magnitude of current becomes,

$$I_{m\_new} = I_m + \Delta I_m \qquad (5)$$

The reference current generation from v_{ac}, i_{ac}, P_{ref}, Q_{ref} can be shown in a simple block diagram in fig. 2.

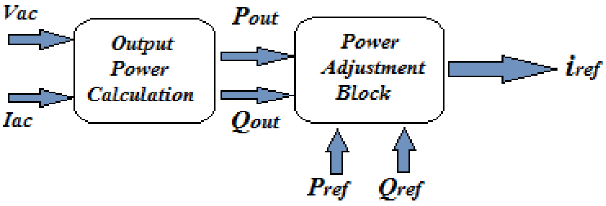

Fig. 2 Basic block diagram of reference current generation

C. CMASDM

Now, by using equation (3) and (5), the reference voltage for ASDM, the pulse generation block, can easily be produced [13]

$$|\bar{v}_{ref}| = \frac{V_{CC}}{V_{DC}}\left(|\bar{v}_{ac}|^2 + \omega^2 L^2 I_{m\_new}\right)^{1/2} \qquad (6)$$

$$\angle\theta_{ref} = tan^{-1}\left(\frac{\omega L\, I_{m\_new}}{|\bar{v}_{ac}|}\right) \qquad (7)$$

Where, ω = 2πf and, L is the output inductance of the inverter. The basic block diagram of CMASDM is shown below.

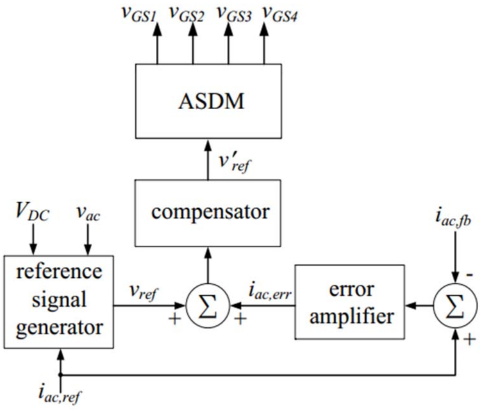

Fig. 3 Basic block diagram of working principle of CMASDM [13]

Here, the four pulse signals are generated by the control of v_{ref}. The pulses generate the required output current from the inverter. The relation between the output current and v_{ref} is [13]

$$i_{ac} = \frac{k \,.\, v_{ref} - v_{ac}}{j\omega L} \qquad (8)$$

Where, k is a constant, which depends on the CMASDM system, and L is the output inductance. So, this block generates the desired pulses for reference power and var, and thus the required output current can be produced just within one cycle.

III. RESULTS AND DISCUSSIONS

For simulation, at first, it has been assumed that a 1 kVA inverter is supplying power at 0.8 lagging power factor. So, P = 0.8 pu and Q = 0.6 pu The whole simulation is done by maintaining per-unit method for simplicity. Three cases have been considered for the comparison. Firstly, the real power assumed constant, and only reactive power is changed to 0.4 pu then the reactive power kept constant, while the real power was reduced to 0.65 pu and then finally both the active and reactive powers are changed. For these three cases, it was clear that the proposed algorithm is way faster than the iterative method. The simulation results are shown below. All the cases are started from the lagging 0.8 p.f. point, i.e., P = 0.8 pu and Q = 0.6 pu.

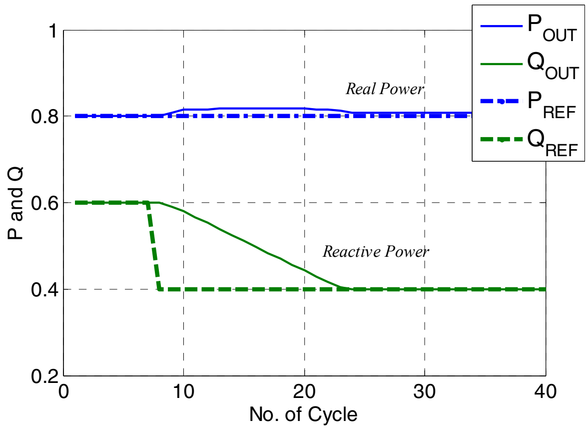

Fig. 4a Real (P) and reactive (Q) power for case I using iterative algorithm

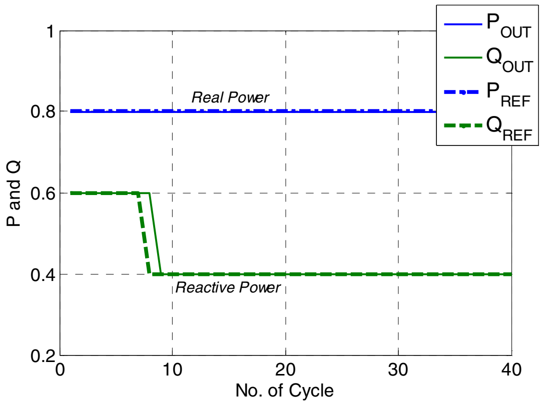

Fig. 4b Real (P) and reactive (Q) power for case I using proposed algorithm

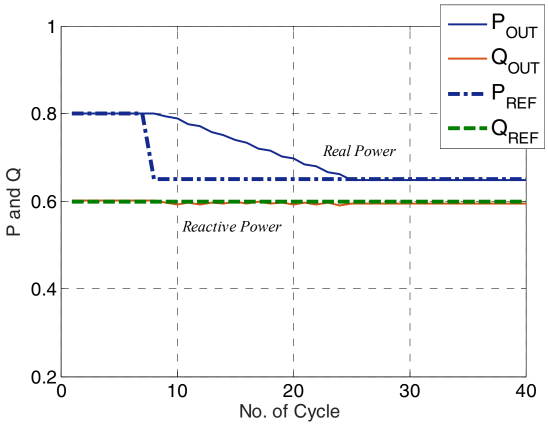

Fig. 5a Real (P) and reactive (Q) power for case II using iterative algorithm

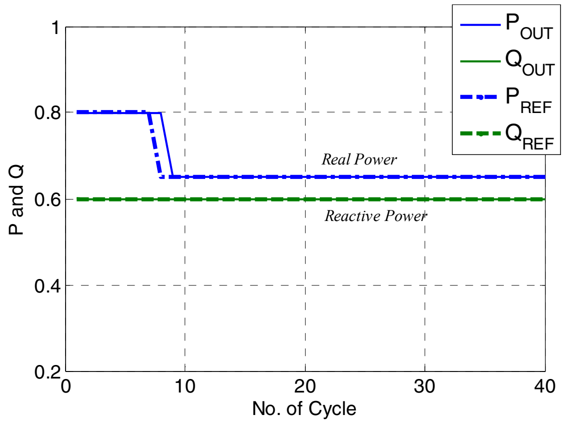

Fig. 5b Real (P) and reactive (Q) power for case II using proposed algorithm

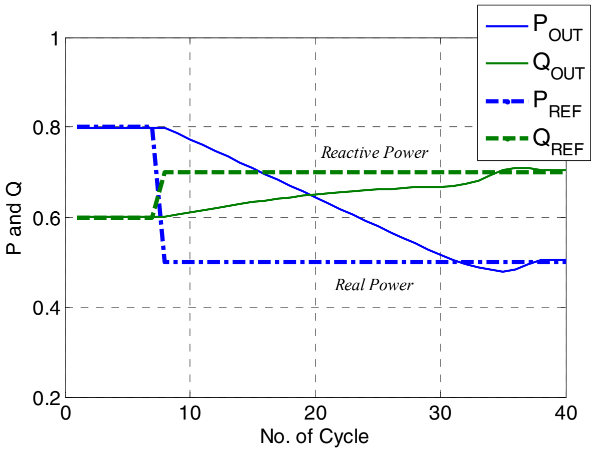

Fig. 6a Real (P) and reactive (Q) power for case III using iterative algorithm

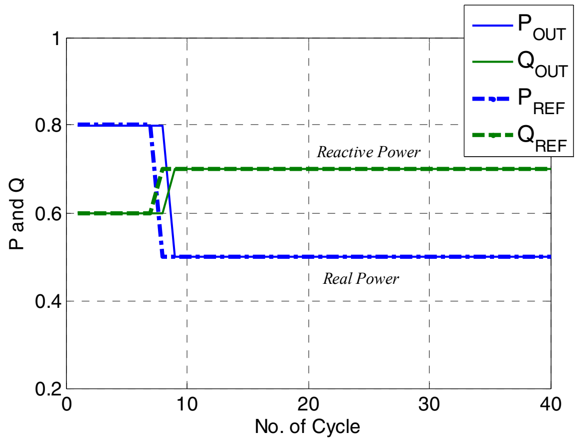

Fig. 6b Real (P) and reactive (Q) power for case III using proposed algorithm

A. Case I:

In this case, the real power P is kept constant, but the reactive power Q is changed from 0.6 pu to 0.4 pu. The proposed power adjustment method changes the power just after one ac cycle (Fig. 4b), But when the iterative method is used, the output power is adjusted to the reference power after almost 17 cycles. also, there occurs a transient in the real power output (Fig 4a).

B. Case II:

For case II, the reactive power output (Q var) is kept constant at 0.6 pu. But the reference of real power P is changed abruptly from 0.8 to 0.65 pu. This rapid change in real power can be adjusted very shortly by proposed fast algorithm (Fig 5b), but the iterative method takes almost 18 ac cycles to produce stable output. It can be seen (Fig 5a) that the proposed algorithm takes only one main cycle here as like as the previous case.

C. Case III:

For this case, we assumed that both the real and reactive power (P and Q) has to be altered. The new P changes to 0.5 pu, and the Q increased to 0.7 pu. For this case, the iterative method needs more than 30 cycles to stabilize the output (Fig 6a). And again, there are ripples in the power waves. But the proposed algorithm needs one cycle again (Fig 6b). And the ripple in the wave is very much undetectable.

For above three cases, a brief comparison between two methods is represented in Table I.

TABLE I

COMPARISON OF TWO ALGORITHMS FOR DIFFERENT CASES

Case	Power Adjusting Time (ms)		Ripple in Power during changing	
	Iterative method	Proposed method	Iterative method	Proposed method
Case I	340	20	High	Very low
Case II	360	20	High	Very low
Case III	600	20	High	Very low

IV. CONCLUSION

This paper proposes a new fast and effective algorithm for generating reference current instead of slow iterative process along with the CMASDM for single phase grid-tied PV inverter. In this paper, real and reactive power control of PV inverter using new algorithm is evaluated and compared with the iterative method of control. The proposed fast algorithm can significantly increase the response time of PV inverter to generate desired active and reactive power, without altering the simplicity of calculation and moreover, reduction in computational burden is still present. Computer simulations for comparing proposed algorithm and iterative method are shown to verify the efficacy of suggested new algorithm.

REFERENCES

[1] Li, Xiaodong, and Ashoka KS Bhat. "A utility-interfaced phase-modulated high-frequency isolated dual LCL DC/AC converter." IEEE Transactions on Industrial Electronics 59, no. 2 (2012): 1008-1019.

[2] Cagnano, Alessia, Enrico De Tuglie, Marco Liserre, and Rosa A. Mastromauro. "Online optimal reactive power control strategy of PV inverters." IEEE Transactions on Industrial Electronics 58, no. 10 (2011): 4549-4558.

[3] Sinsukthavorn, Worpong, Egon Ortjohann, Alaa Mohd, Nedzad Hamsic, and Danny Morton. "Control strategy for three-/four-wire-inverter-based distributed generation." IEEE Transactions on Industrial Electronics 59, no. 10 (2012): 3890-3899.

[4] Maknouninejad, Ali, Nasser Kutkut, Issa Batarseh, and Zhihua Qu. "Analysis and control of PV inverters operating in VAR mode at night." InInnovative Smart Grid Technologies (ISGT), 2011 IEEE PES, pp. 1-5. IEEE, 2011.

[5] Saitou, Makoto, and Tosihisa Shimizu. "Generalized theory of instantaneous active and reactive powers in single-phase circuits based on Hilbert transform." In Power Electronics Specialists Conference, 2002. pesc 02. 2002 IEEE 33rd Annual, vol. 3, pp. 1419-1424. IEEE, 2002.

[6] Bojoi, Radu Iustin, Leonardo Rodrigues Limongi, Daniel Roiu, and Alberto Tenconi. "Enhanced power quality control strategy for single-phase inverters in distributed generation systems." IEEE Transactions on Power Electronics 26, no. 3 (2011): 798-806.

[7] Zhang, Qi, Xiang-Dong Sun, Yan-Ru Zhong, Mikihiko Matsui, and Bi-Ying Ren. "Analysis and design of a digital phase-locked loop for single-phase grid-connected power conversion systems."IEEE Transactions on Industrial Electronics 58, no. 8 (2011): 3581-3592.

[8] Liu, Liming, Hui Li, Zhichao Wu, and Yan Zhou. "A cascaded photovoltaic system integrating segmented energy storages with self-regulating power allocation control and wide range reactive power compensation." IEEE Transactions on Power Electronics 26, no. 12 (2011): 3545-3559.

[9] Sampaio, Leonardo P., Moacyr AG de Brito, Guilherme de A. e Melo, and Carlos A. Canesin. "Grid-tie three-phase inverter with active power injection and reactive power compensation." Renewable Energy 85 (2016): 854-864.

[10] Sun, Pengwei, Chuang Liu, Jih-Sheng Lai, and Chien-Liang Chen. "Grid-tie control of cascade dual-buck inverter with wide-range power flow capability for renewable energy applications."IEEE transactions on power electronics 27, no. 4 (2012): 1839-1849.

[11] Liu, Chuang, Pengwei Sun, Jih-Sheng Lai, Yanchao Ji, Mingyan Wang, Chien-Liang Chen, and Guowei Cai. "Cascade dual-boost/buck active-front-end converter for intelligent universal transformer." IEEE Transactions on Industrial Electronics 59, no. 12 (2012): 4671-4680.

[12] Chang, Chia-Hsi, Yu-Hui Lin, Yaow-Ming Chen, and Yung-Ruei Chang. "Simplified reactive power control for single-phase grid-connected photovoltaic inverters." IEEE Transactions on Industrial Electronics 61, no. 5 (2014): 2286-2296.

[13] Chen, Yaow-Ming, Chia-Hsi Chang, and Kuan-Yu Liu. "Grid-tied inverter with current-mode asynchronous sigma-delta modulation." In 2009 IEEE Energy Conversion Congress and Exposition, pp. 928-933. IEEE, 2009.