Fixed Point Arithmetic Implementation of Digital Proportional - Resonant Single-Phase Current Controllers

by Iwan Setiawan

Fixed Point Arithmetic Implementation of Digital Proportional - Resonant Single-Phase Current Controllers

Iwan Setiawan
Electrical Engineering Department
Universitas Diponegoro
Semarang, Indonesia
iwansetiawan@live.undip.ac.id

Achmad Hidayatno
Electrical Engineering Department
Universitas Diponegoro
Semarang, Indonesia
achmad.hidayatno@gmail.com

Haris Kuspranoto
Electrical Engineering Department
Universitas Dian Nuswantoro
Semarang, Indonesia
harislightace@gmail.com

Trias Andromeda
Electrical Engineering Department
Universitas Diponegoro
Semarang, Indonesia
trias1972@gmail.com

Mochammad Facta
Electrical Engineering Department
Universitas Diponegoro
Semarang, Indonesia
mochfacta@gmail.com

Hermawan
Electrical Engineering Department
Universitas Diponegoro
Semarang, Indonesia
hermawan.60@gmail.com

***Abstract*—The main objective of this paper is to present practical digital implementation of Proportional Resonant-based-single phase current controller for low-cost Digital Signal Controllers (DSCs). In this work, the PR controller was developed by using a 16-bit fixed-point arithmetic with Q15 data format, and the codes were embedded in a low-cost 16-bit DSC to control 50 Hz AC current of single-phase inverter systems. Although the PR controller is implemented digitally, the designed processes of the PR current controller in this paper are served in continuous model. The discreet model than derived by using a simple backward difference approximation. To be easily adopted in different size of single-phase inverter systems, all the state variables and its parameters of the PR controller are represented in Q15 number format and manipulated in the same data format. Experimental and testing results show the effectiveness of the proposed digital implementation technique of the PR current controller.**

Keywords*—fixed-point arithmetic, backward discretization, proportional-resonant control, single-phase current controller, single phase inverter systems,

I. Introduction

Single-phase AC current control systems are widely used in many inverter applications. In many cases, the single-phase current controller could be found in the inner loop of the single-phase power systems such as in high performance single-phase UPSs [1][2], grid-tied inverter systems [3][4], active filters [5], etc.

Up to now, various single-phase AC current control strategies have been proposed by some researchers. Due to its simplicity and at the same time have a fast-transient response, hysteresis-based control strategies or its variance [6-8] probably is one of the popular strategies which could be adopted for controlling single-phase AC current. However, due to its nature, this control strategy generally in practice will generate unacceptable harmonics

Another simple control strategy that could be used for controlling single-phase AC current is a conventional proportional plus integral-based control method [9]. This control system is widely adopted in the control process with constant reference, however, for the plant with time-varying signal reference such as in AC current control systems, this strategy will suffer from the steady-state error.

To overcome the weaknesses of the hysteresis and conventional PI control strategies, several advance control strategies for controlling single-phase AC current have been proposed in the literature, such as model predictive control [10], sliding mode controller [11], repetitive control [12], Discrete Fourier Transform [13], synchronous d-q reference frame method [14] even Neural network-based current controller [15]. Although these control strategies offer advantages compared with conventional ones, however from the control point of view, these strategies are less intuitive and relatively hard to be implemented.

Due to its good performances mainly in the steady-state response and relatively easy to be implemented, a single-phase current control strategy that probably most be adopted in practice is a proportional resonant (PR)-based controller [16-19]. Different from the conventional PI controller which only has a high gain in low-frequency input, the PR controller has a high gain in a certain selected input frequency, so this controller is very appropriate for controlling a plant output with a time-varying sinusoidal signal reference.

Although the PR controller and its variances have been discussed a lot in the literatures. But, many of them ignore the presentation of the practical implementation aspects of the controller.

The main objective of this paper is to present practical technique of digital implementation of single-phase AC inverter current Proportional-Resonant (PR) control. To be computationally efficient, the PR current controller is developed by using a fixed-point arithmetic-based fast computation technique, and the controller is embedded in a low cost 16-bit wide fixed-point digital signal controller. In this work, the designed PR algorithm is implemented to control 50 Hz AC current of a single-phase inverter system.

The remaining of this paper is organized as follows. Section 2 describes the complete system model. The short theory of the 16-bit fixed-point number in Q15 format will be introduced in Section 3. While, the practical technique of digital realization of the PR controller will be discussed in Section 4. Next, in Section 5, the experimental results will be presented. Finally, the conclusions are drawn in Section 6.

II. SYSTEM MODEL

Fig 1. Shows the simplified topology of the single-phase inverter current controller under study. In this case, PR and SPWM blocks respectively denote Proportional-Resonant controller and Sinusoidal Pulse Width Modulation which generally implemented as software modules in Digital Signal Processor or microcontroller-based single-phase AC inverter control systems.

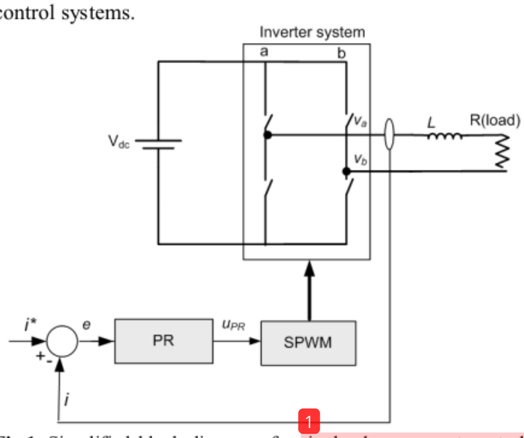

Fig.1. Simplified block diagram of a single-phase current control system

A. Proportional-Resonant Controller

One of the popular controllers suitable for tracking a sinusoidal wave reference is the Proportional-Resonant controller. Unlike a conventional PI controller that only has high gain in a low-frequency input signal, the PR controller could have high gain in a certain frequency input signal. With this inherent characteristic, the PR controller is suitably used for controlling systems with time-varying control references such as AC signals.

Mathematically, the transfer function of the PR controller could be represented as shown at eq.1 [20].

$$H_{pr}(s) = \frac{U_{pr}(s)}{e(s)} = K_p + \frac{2K_r\omega_c s}{s^2+2\omega_c s+\omega_0{}^2} \tag{1}$$

Where U_{pr} dan e respectively are output and error input signal of the PR controller, K_p and K_r respectively are proportional and resonant gain of the controller, whereas ω_0 is the resonant frequency, and ω_c is a cut-off frequency that reflects the ability of the PR controller to track input signals in real-time.

The performance of the PR controller practically is determined by the proper values of its parameters. Fig. 2 until Fig.4 show bode plots of the PR control transfer function given in (1).

From the plot of Fig. 2, it is shown that the proportional gain (*Kp*) of controller directly influences the magnitude of the output signal for a wide range of input signal frequencies. Increasing the proportional gain will increase the magnitude of the signal for all band frequencies.

Whereas from Fig. 3, it is clear that the higher gain of resonant (K_r), the magnitude of the frequency around the resonant will be higher. The PR controller with high gain resonant gain will have more capacity to eliminate the steady-state error. The higher of magnitude at the around frequency, the tracking capability of the controller is better.

Finally, from Fig. 4 one can see that the cut-off frequency (ω_c) of the controller directly influence bandwidth. The smaller of the cut-off frequency , the frequency band will be narrower and the system more sensitive to frequency variation and vice versa.

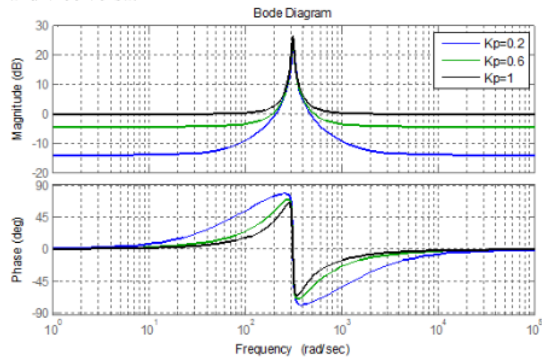

Fig.2. Frequency response of PR controller for $\omega_0=2\pi 50$ rad/s $\omega_c=1$ rad/sec, K_r=20, and several variations of K_p

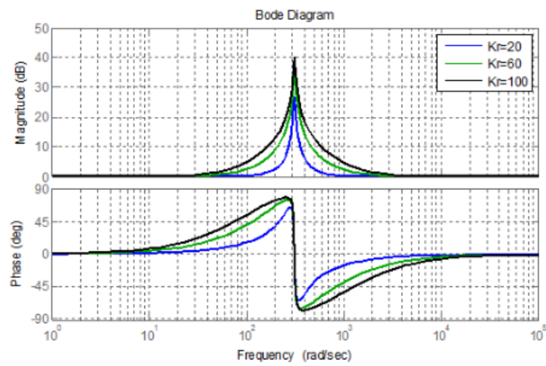

Fig.3. Frequency response of PR controller for $\omega_0=2\pi 50$ rad/s $\omega_c=1$ rad/sec, Kp=1, and several variations of Kr

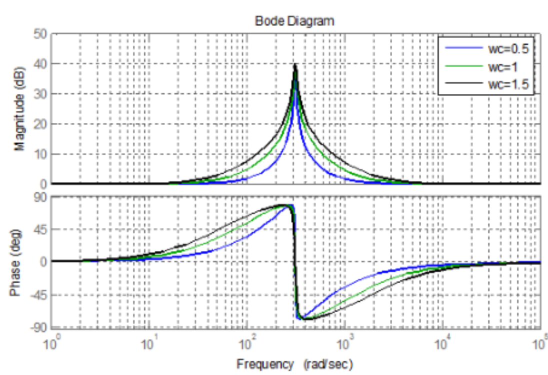

Fig.4. Frequency response of PR controller for $\omega 0=2\pi 50$ rad/s, *Kp*=1, *Kr*=100, and several variations of ωc

B. Single-Phase Inverter Practical Model

Fig. 5 shows a general topology of a single-phase inverter system under study.

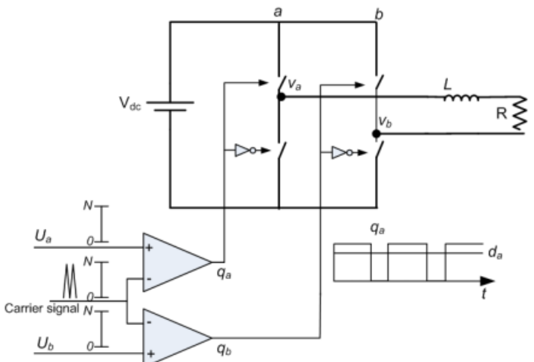

Fig. 5. Single phase inverter system

By using the Kirchhoff voltage law, the current dynamic of the inverter circuit at Fig.5 could be represented as shown in (2)

$$v_{inv} = L\frac{di}{dt} + Ri \tag{2}$$

In this case, the inverter output voltage itself mathematically could be written as shown at (3)

$$v_{inv} = v_a - v_b \tag{3}$$

Where v_a and v_b respectively are the average voltage of upper switch of the inverter leg A and the average voltage of lower switch of the inverter leg B. In inverter system, these two voltages basically depend on the duty cycle or average value of the comparator output pulse signal: q_a and q_b as shown at (4) and (5).

$$v_a = d_a V_{dc} \tag{4}$$

$$v_b = d_b V_{dc} \tag{5}$$

In this case, d_a and d_b respectively are average value of q_a and q_b or the duty cycle of the comparator outputs (PWM signal).

These input - output relations of the comparators mathematically could be represented as shown at (6) and (7).

$$d_a = \frac{1}{N}U_a \tag{6}$$

$$d_b = \frac{1}{N}U_b \tag{7}$$

Where N is maximum value of carrier signal (in microcontroller based PWM), N actually is a integer number associated with the certain PWM register), whereas U_a and U_b respectively are input comparator A and comparator B. From (5) and (6), for input U_a and U_b with the range [0 N], the duty cycle of d_a and d_b will have value in the range [0:1].

Now, by substituting (6) and (7) into (4) and (5), then (3) could be written as shown at (8).

$$v_{inv} = \frac{1}{N}V_{dc}(U_a - U_b) \tag{8}$$

In feedback control system (like PR based controller), the U_a signal practically derived directly from controller output u_{pr} which generally have normalized output range [-1:1]. Whereas U_b signal could be obtained by inverting the u_{pr} signal. Fig 6. and Fig.7 respectively show the signal flow diagram of the control system and the mathematical relations of U_a vs u_{pr} and U_b vs u_{pr}.

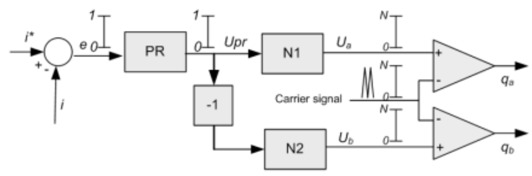

Fig. 6. Control signal flow diagram

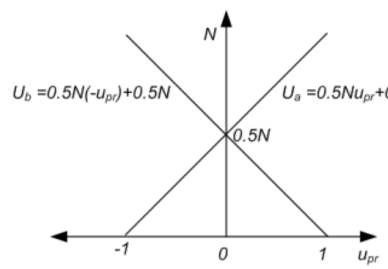

Fig. 7. Relation between U_a vs u_{pr} and U_b vs u_{pr}

Based on Fig.7 the relation between controller output (u_{pr}) and comparator input signals could be written as depicted at (9) and (10).

$$U_a = 0.5Nu_{pr} + 0.5N \tag{9}$$

$$U_b = 0.5N(-u_{pr}) + 0.5N \tag{10}$$

By substituting (9) and (10) to (8), the relation between the inverter voltage output with signal control can be represented by (11)

$$v_{inv} = V_{dc}u_{pr} \tag{11}$$

So now, the dynamic of inverter current due to the change of the control signal output could be represented explicitly by substituting (11) into (2):

$$V_{dc}u_{pr} = L\frac{di}{dt} + Ri \tag{12}$$

By using Laplace transform, the relation of the inverter current with controller output now could be written:

$$H = \frac{I(s)}{U_{pr}(s)} = \frac{(V_{dc}/R)}{(L/R)s+1} \tag{13}$$

For convenience we can also write this transfer function in per-unit variable as shown at (13)

$$\frac{I_{pu}(s)}{U_{pr}(s)} = \frac{1}{Base\_I}\frac{V_{dc}/(R)}{(L/R)s+1} \tag{14}$$

III. 16-Bit Fixed Point Arithmetic Using Q15 Data Format

Practically, for the small embedded system application based on fixed point arithmetic, the fixed-point number format that is commonly used is the Q15 format. Using this fixed-point format, real numbers (floating point type) with a range of values between -1: 0.9996 are mapped to signed int numbers with a range of values between -32768: 32767.

In this data format, every real number z between [-1:0.9996 (~1)], could be represented in Mantissa-Exponent format as shown at (15)

$$z = M(2^{-15}) \tag{15}$$

Where M is the mantissa of the real number with the range: -32768: 32767, whereas 2^{-15} is exponent or scale factor of the fixed-point number.

A. Q15 Format Multiplication

Multiplication of two fixed point numbers is done by multiplying the two numbers and adding the two scale factors. The following equation 6.10 shows the multiplication of two real numbers in Q15 format.

$$z = z_1 x z_2 = M_1 x M_2 (2^{-30}) \tag{16}$$

Multiplying the two signed integer number M1xM2 above will produce 30 bits integer number plus two signed bits. So in order the results to be stored again in the 16-bit variable, the result should be shift 15 bit to the right as shown at (17).

$$z = z_1 x z_2 = ((M_1 x M_2) >> 15)(2^{-15}) \tag{17}$$

B. Q15 Format Addition/Subtraction

The main requirement for addition / subtraction of the fixed-point variables is the scale factor of the two numbers must be the same. Eq. (18) below shows the addition/ subtraction of two real numbers in the Q15 data format.

$$z = z_1 \pm z_2 = (M_1 \pm M_2)(2^{-15}) \tag{18}$$

However, differ from the multiplication result, the addition of the two fixed-point numbers practically could result overflow bit. So, to avoid the overflow result, the saturation technique as shown at Fig.8 could be applied to the fixed-point addition/subtraction.

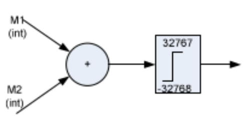

Fig. 7. Saturation technique applied to the fixed-point addition/substraction to hinder overflow

IV. Practical Digital Realization of PR Controller

In this section, the discussion of practical techniques for implementing the PR controller digitally will be delivered.

By applying the backward difference approximation to Resonant Controller in (1), the output dynamic of the resonant controller could be represented as shown at (19)

$$u_R(k) = a_2 u(k-2) + a_1 u(k-1) + b_1 e(k-1) + b_0 e(k) \tag{19}$$

Where

$$a_2 = -\frac{1}{1+2\omega_c T+\omega_0{}^2 T^2} \tag{21}$$

$$a_1 = \frac{(2+2\omega_c T)}{1+2\omega_c T+\omega_0{}^2 T^2} \tag{22}$$

$$b_1 = -\frac{2Kr\omega_c T}{1+2\omega_c T+\omega_0{}^2 T^2} \tag{23}$$

$$b_0 = -b_1 = \frac{2Kr\omega_c T}{1+2\omega_c T+\omega_0{}^2 T^2} \tag{24}$$

By refer to (19), the block diagram of the resonant controller could be depicted as shown at Fig.8.

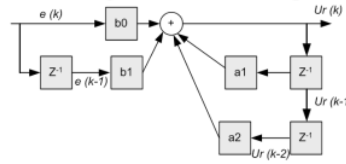

Fig. 8. Block diagram of the resonant controller

Based on (19), it is clear that the operation of the controller basically just involved two arithmetic operation: four multiplications and three additions.

Due to the controller will be implemented arithmetically by using fixed point arithmetic with Q15 data format, we should care with the values of the resonant controller parameters: a_2, a_1, b_1, and b_0. In the case, we should guarantee that for easiness of the implementation of the fixed-point multiplication, the real value of the constants should be in the range [-1:0.99996(~1)].

By analyzing the parameters of the digital PR controller for T=0.0001 s, $\omega_0 = 2\pi 50$ rad/s, $\omega_c = 1$ rad/s with K_r in the range 0 until 5000, the output resonant controller practically could be rewritten as shown at (25).

$$u_R(k) = a_2 u(k-2) + (a_1/2)u(k-1) + (a_1/2)u(k-1) + b_1 e(k-1) + b_0 e(k) \tag{25}$$

And finally, by combining the resonant controller output with the proportional controller output, the output of the PR controller could be computed by using (26).

$$u_{PR}(k) = K_P e(k) + u_R(k) \tag{26}$$

Fig. 9 shows the complete block diagram of the PR controller by using 16-bit fixed-point Q15 data format which proposed in this works.

The output of the PR controller than normalized by using (9) and (10) before sent to the input channel of the PWM comparator.

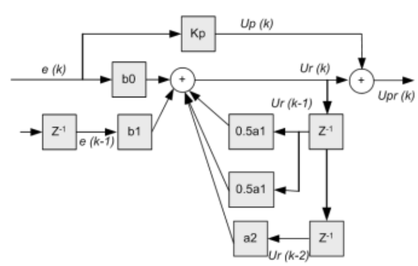

Fig. 9. The complete block diagram of the PR controller which implemented in this work

V. Experimental Results

To test the performance of the developed PR controller, we have built single-phase inverter system prototype to drive LR circuit as shown at Fig.10. The hardware used in this work is a low-cost 20 MHz 16-bit DSC dsPIC30F4011.

The PR controller is updated every 0.0001 second, and the controller output is sent to double slope PWM channels with 20KHz carrier frequency. Table 1 and table 2 respectively show the parameters of the circuit and the PR controller used in this works. For the PR controller parameters list in Table 2, the PR constants used in the code is shown at Table 3.

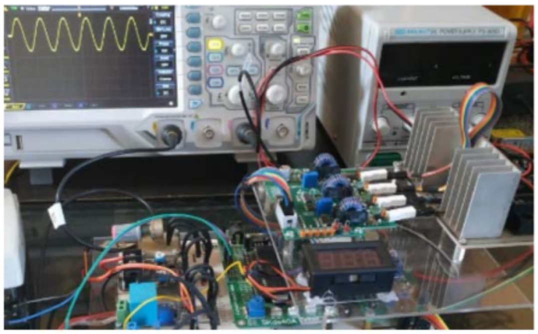

Fig. 10. Experimental setup of single-phase inverter

Table 1. The inverter system Paramaters

Parameter	value
V_{dc}(V)	350
R (ohm)	50,100
L (H)	0.04

Table 2. The PR controller Paramaters

Parameter	Value
K_p	0.8
K_r	2000
ω_c	1
ω_0	314

Table 3. The constans of PR controller based on Table 2 (T=0.0001)

The PR controller constants	Value
a_2	0.9988
a_1	1.9978
b_1	-0.3995
b_0	0.3995

In this experiment, we generate 50 Hz current reference by using 256 bit-wide look up table. The magnitude of the current reference could be varied by turning potentiometer connected to the internal ADC of the DSC.

To test the PR controller performance, we have tried several values of the current reference magnitude and loads. Fig.11 until Fig. 14 show tracking capability of the PR controller with the different reference magnitudes and loads. In Fig. 11 and Fig.12, the load is set to 50 Ohm, with the sinusoidal current reference magnitude respectively about 1 A and 1.5 A, whereas in Fig 13 and 14, the load is set to 100 Ohm, with the sinusoidal current reference magnitude respectively about 2 A and 2.0 A. From all the figures, the controller output could track the 50 Hz current references almost perfectly, there are almost no delay nor a steady state error for all the inverter current output.

From Fig. 15, we also can see that with 20 MHz PWM carrier frequency, the current output ripple could almost be ignored. The performance of the developed current controller also can be seen from Fig. 16. By using varying current reference magnitude, the current output could track the reference instantly.

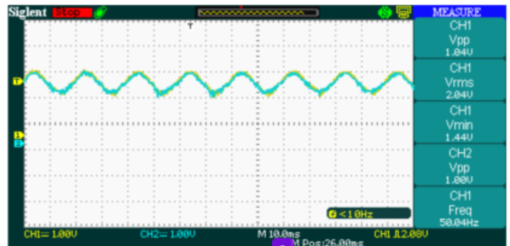

Fig. 11. The reference (yellow) and the actual current (green) of the inverter

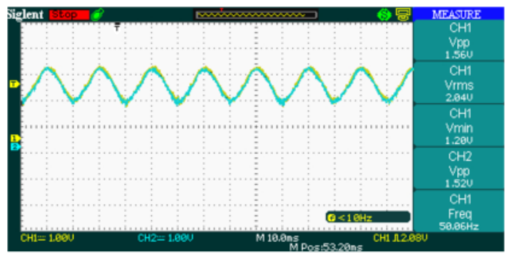

Fig. 12. The reference (yellow) and the actual current (green) of the inverter

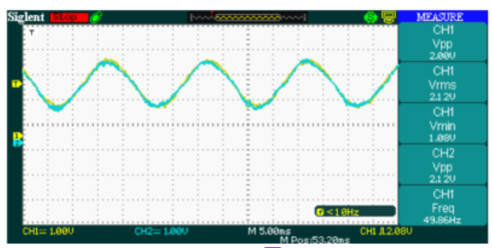

Fig. 13. The reference (yellow) and the actual current (green) of the inverter

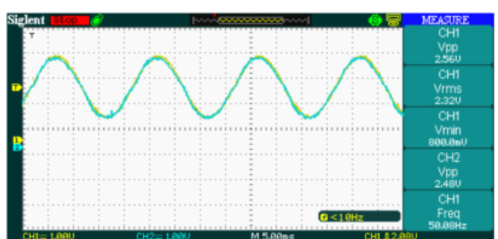

Fig. 14. The reference (yellow) and the actual current (green) of the inverter

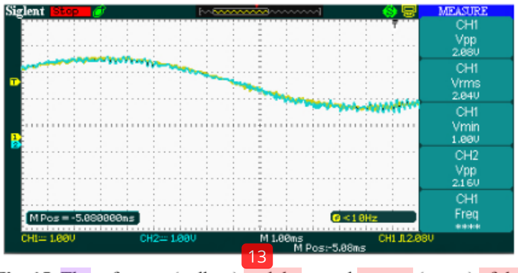

Fig. 15. The reference (yellow) and the actual current (green) of the inverter

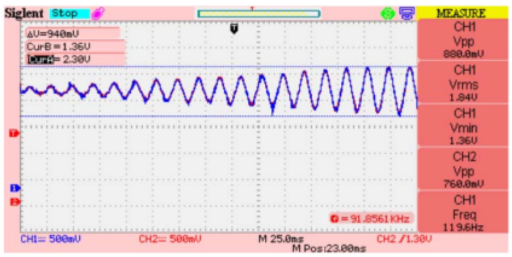

Fig. 16. The tracking capability of the controller: The reference (red) and the actual current (blue) of the inverter

VI. Conclusion

The practical technique of digital implementation of Proportional Resonant-based single-phase current controller in the low-cost DSC have been presented. In this work, all the state variables of PR controller are represented and manipulated by using 16-bit fixed point with Q15 data format. Although the DSC hardware specification in this work is relatively low (just 20 MHz working frequency), however by refer to experimental results, the performance of the implemented PR controller is satisfactory. From the oscilloscope output, we can see that the inverter current output could track the reference almost perfectly with no delay nor steady state error. In the future work, we will investigate the performance of the PR controller for the single phase grid tied inverter.

Acknowledgment

This research was financially supported by The Faculty of Engineering, Diponegoro University, Indonesia through Strategic Research Grant 2020 with contract number [2496/STE11/UN7.5.3.2/PP/2020].

References

[1] Monfared, Mohammad. "A simplified control strategy for single-phase UPS inverters." Bulletin of the Polish Academy of Sciences Technical Sciences 62.2 (2014): 367-373.

[2] Komurcugil, Hasan, et al. "An extended Lyapunov-function-based control strategy for single-phase UPS inverters." IEEE Transactions on Power Electronics 30.7 (2015): 3976-3983.

[3] Islam, Monirul, Saad Mekhilef, and Mahamudul Hasan. "Single phase transformerless inverter topologies for grid-tied photovoltaic system: A review." Renewable and Sustainable Energy Reviews 45 (2015): 69-86.

[4] Komurcugil, Hasan, et al. "Model-Based Current Control for Single-Phase Grid-Tied Quasi-Z-Source Inverters with Virtual Time Constant." IEEE Transactions on Industrial Electronics (2018).

[5] Kanagavel, Rameshkumar, et al. "A Novel Current Control Technique for Photo Voltaic Integrated Single Phase Shunt Active Power Filter." International Journal of Renewable Energy Research (IJRER) 7.4 (2017): 1709-1722.

[6] Rahim, Nasrudin Abd, and Jeyraj Selvaraj. "Implementation of hysteresis current control for single-phase grid connected inverter." Power Electronics and Drive Systems, 2007. PEDS'07. 7th International Conference on. IEEE, 2007.

[7] F. Wu, L. Zhang, and Q. Wu, "Simple unipolar maximum switching frequency limited hysteresis current control for grid-connected inverter," IET Power Electron., Vol. 7, No. 4, pp. 933-945, Apr. 2014.

[8] F. Wu, X. Li, and J. Duan, "Improved elimination scheme of current zero-crossing distortion in unipolar hysteresis current controlled grid-connected inverter," IEEE Trans. Ind. Inform., Vol. 11, No. 5, pp. 1111-1118, Oct. 2015.

[9] Cherati, S. M., et al. "Design of a current mode PI controller for a single-phase PWM inverter." Applied Power Electronics Colloquium (IAPEC), 2011 IEEE. IEEE, 2011.

[10] Vazquez, Sergio, et al. "Model predictive control for power converters and drives: Advances and trends." *IEEE Transactions on Industrial Electronics* 64.2 (2017): 935-947.

[11] Makhamreh, Hamza, and Osman Kukrer. "Discrete time sliding mode control of single phase lcl grid-inverter." *2017 IEEE International Conference on Industrial Technology (ICIT)*. IEEE, 2017.

[12] Evran, Fatih. "Plug-in repetitive control of single-phase grid-connected inverter for AC module applications." *IET Power Electronics* 10.1 (2017): 47-58.

[13] Hwang, Uiseon, Oh Yang, and Wonsup Chung. "The Output Current Controller of a Single-phase Grid-connected PV Inverter in Discrete Fourier Transform." International Journal of Control and Automation 6.5 (2013): 263-276.

[14] Zhang, Richard, et al. "A grid simulator with control of single-phase power converters in DQ rotating frame." Power Electronics Specialists Conference, 2002. pesc 02. 2002 IEEE 33rd Annual. Vol. 3. IEEE, 2002.

[15] Rukonuzzaman, M., and M. Nakaoka. "Single-phase shunt active power filter with adaptive neural network method for determining compensating current." *IECON'01. 27th Annual Conference of the IEEE Industrial Electronics Society (Cat. No. 37243)*. Vol. 3. IEEE, 2001.

[16] Kuspranoto, Abdul Haris, et al. "Design and Development of Injection Current Control On Inverter-Based Proportional Resonant Method." 2018 5th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE). IEEE, 2018.

[17] Teodorescu, Remus, et al. "Proportional-resonant controllers and filters for grid-connected voltage-source converters." IEE Proceedings-Electric Power Applications 153.5 (2006): 750-762.

[18] Ramesh, V., and Srihari Mandava. "Microgrid Design and Control Using a Discrete Proportional Resonant Controller." International Journal of Renewable Energy Research (IJRER) 5.4 (2015): 1041-1048.

[19] I. Colak, E. Kabalci and G. Keven, "The Effects of PR Control in Three-Level Single-Phase Multilevel Inverter," 2019 8th International Conference on Renewable Energy Research and Applications (ICRERA), Brasov, Romania, 2019, pp. 821-826, doi: 10.1109/ICRERA47325.2019.8996513.

[20] Wang, Xiaoyuan, et al. "A Proportional Resonant Control Strategy for Efficiency Improvement in Extended Range Electric Vehicles." Energies 10.2 (2017): 204.

Fixed Point Arithmetic Implementation of Digital Proportional - Resonant Single-Phase Current Controllers

ORIGINALITY REPORT

17%	%	17%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Iwan Setiawan, Mochammad Facta, Hermawan, Trias Andromeda, Mauridhi Hery Purnomo, Taufik. "Sinusoidal Current Control Strategies for Single Phase Grid-Connected Renewable Power Generation Systems", 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), 2020 Publication	6%
2	Arifin Wibisono, Mochammad Facta, Iwan Setiawan. "An Average Current Control Method in Multiphase Interleaved Bidirectional DC/DC Converter Connected on DC Micrograds", 2021 12th International Renewable Engineering Conference (IREC), 2021 Publication	3%
3	Ujjwol Tamrakar, Dipesh Shrestha, Naresh Malla, Zhen Ni, Timothy Hansen, Indraman Tamrakar, Reinaldo Tonkoski. "Comparative Analysis of Current Control Techniques to	1%

Support Virtual Inertia Applications", Applied Sciences, 2018
Publication

4 Saban Ozdemir. "Z-source T-type inverter for renewable energy systems with proportional resonant controller", International Journal of Hydrogen Energy, 2016 1%
Publication

5 Catur Nofianto, Mochammad Facta, Omar Abouzeid, Hermawan. "Analysis of Electrical Energy Consumption for Lighting System in Polyclinic, Radiology, and Patient Rooms of Hospital Building", 2020 7th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), 2020 1%
Publication

6 K. Hussain*, Puli Sridhar. "Multi-Objective Flower Pollination Algorithm Based Controller for UPQC Including Hybrid Power Source", International Journal of Innovative Technology and Exploring Engineering, 2020 1%
Publication

7 Ringgi Cahyo Dwiputra, Putu Wuri Handayani, Fathia Prinastiti Snnarso, Muhammad Hafizhuddin Hilman. "The Influence of Electronic Word-of-Mouth Information Quality Dimensions on Consumer Product Purchase 1%

in Online Marketplace", 2021 International Conference on Advanced Computer Science and Information Systems (ICACSIS), 2021
Publication

8	Frede Blaabjerg Blaabjerg, Keliang Zhou Zhou, Danwei Wang Wang, Yongheng Yang Yang. "Periodic control of power converters", Institution of Engineering and Technology (IET), 2016 Publication	<1%
9	G. Jayaramaiah, B. Fernandes. "Novel Voltage Controller for Stand-alone Induction Generator using PWM-VSI", Conference Record of the 2006 IEEE Industry Applications Conference Forty-First IAS Annual Meeting, 2006 Publication	<1%
10	Jin-Hyuk Park, Hae-Gwang Jeong, Kyo-Beum Lee. "Second order harmonics reduction technique using model predictive control for household energy storage systems", 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014, 2014 Publication	<1%
11	Bo Zhou. "Steady-State Stability Analysis of HVDC Systems with Digital Control", IEEE Transactions on Power Apparatus and Systems, 1983 Publication	<1%

12	Hasan Komurcugil, Necmi Altin, Saban Ozdemir, Ibrahim Sefa. "An Extended Lyapunov-Function-Based Control Strategy for Single-Phase UPS Inverters", IEEE Transactions on Power Electronics, 2015 Publication	<1 %
13	Xiongfei Wang, Frede Blaabjerg, Marco Liserre. "An active damper to suppress multiple resonances with unknown frequencies", 2014 IEEE Applied Power Electronics Conference and Exposition - APEC 2014, 2014 Publication	<1 %
14	Cirrincione. "Current Harmonic Compensation by a Single-Phase Shunt Active Power Filter Controlled by Adaptive Neural Filtering", IEEE Transactions on Industrial Electronics, 2009 Publication	<1 %
15	Iwan Setiawan, Mochammad Facta, Trias Andromeda, Hermawan, Abdul Syakur. "An Optimum Tuning Method for DC Bus Voltage Regulation in Double Stage Off-Grid PV Systems", 2021 8th International Conference on Information Technology, Computer and Electrical Engineering (ICITACEE), 2021 Publication	<1 %
16	Kazem Hejranfar, Kaveh Parseh. "Numerical simulation of structural dynamics using a	<1 %

high-order compact finite-difference scheme", Applied Mathematical Modelling, 2016
Publication

17	Trung-Kien Vu, Se-Jin Seong. "Comparison of PI and PR Controller Based Current Control Schemes for Single-Phase Grid-Connected PV Inverter", Journal of the Korea Academia-Industrial cooperation Society, 2010 Publication	<1 %
18	Jinghua Zhou, Shuang Xu, Riming Shao, Liuchen Chang. "Predictive current controller and compensator-based discrete current controller for single-phase bridge inverters", Journal of Power Electronics, 2022 Publication	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		