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Reduction in Current THD of Grid Parallel Inverters Using Randomized PR Control

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ABSTRACT

In grid connected system, unity power factor current injection into the grid is vital. This can be achieved by choosing the right inverter topology, passive filter components, current controllers, and PWM switching scheme. This paper compares the output current harmonics profile between when using the conventional proportional resonant (PR) current controller and when using the modified PR current controller. By applying the latter technique, via experimental validation using TMS320F2812, the THD of the injected grid current in a parallel connected inverters system is improved.

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1. INTRODUCTION

Distributed generation uses renewable energy sources that include solar, wind, wave, hydro, etc. These technologies convert natural resources to more usable energy that is electricity. Normally, distributed generation systems are of small scale, scattered around and closer to end users [1],[2]. Most importantly, these systems use inverters to integrate the generation part into the grid and must ensure that they supply the standard quality of power [3]. Inverters have to fulfil several important functions before the outputs can be fed to the utility grid [4]. However, the inverter systems do have their drawbacks which comes from the switching process and non-linearity in the components used. The levels of distortion during conversion and control process are very difficult to avoid. At the end, undesireable current and voltage harmonics appear at the inverter output, thus will potentially contribute to higher THD value in grid network. The problems will enhance when several inverter systems are connected together in parallel and feed the utility grid. This is because, each inverter output voltage and current must be synchronized to the grid voltage and current. Yet, when applying this synchronization method and with interaction of a closely coupled inverter systems may potentially increase the grid current and voltage THD values [5].

Studies have been done by many researchers in order to improve grid power quality thus reduce the grid THD value to not exceed the limitation by IEEE standard [6]. In [7], space vector pulse width modulation (SVPWM) is proposed as a control method in a grid connected three phase solar PV system. Results show that the feed forward grid voltage compensation improve the grid harmonic spectrum and thus achieve the required THD. However, any imperfect compensation may cause harmonics in grid current. Other researchers introduced proportional integral (PI) controller and proportional resonant (PR) controller to be used together in order to control the impacts of grid voltage distortion. In the paper, PI controller controls the inner inverter output current control loop whilst a combination of both PI and PR controller regulate the outer grid current control loop [8]. Unfortunately, this strategy may increase the complexity of computational algorithm. Other research as in [9] proposed a PR controller and added several harmonic compensators (HC) to reduce THD values. This method is also believed to increase the same complexity of the computational algorithm. Else, in [10]-[12], repetitive controller-based harmonic elimination is used. Yet, the performance of this technique is sensitive to frequency variation and may affect the stability as mentioned in [13]. In this paper, the advantage of PR controller is taken and randomization of the gain is considered for power quality improvement especially in reducing the current THD value.

2. RESEARCH METHOD

2.1. PR Control Method

In this technique, the weakness of the PI current control technique regarding the steady state error can be dealt with [14]. This means that the measured output current will be equally same to the demand current. Based on [9], the analogue transfer function of the PR current controller is defined as:

$$G_{PR}(s) = K_P + K_R \frac{s}{s^2+\omega_o^2} \tag{1}$$

By using the Tustin transformation, the analogue equation above can be transformed to discrete function in z domain. By substituting $\boldsymbol{s}$ with $\frac{\mathbf{2}}{\boldsymbol{T}}\frac{\mathbf{1-z^{-1}}}{\mathbf{1+z^{-1}}}$, Equation 1 becomes:

$$G_{PR}(z) = \frac{\left(\frac{4K_P}{T^2}\right)\left(\frac{1-2z^{-1}+z^{-2}}{1+2z^{-1}+z^{-2}}\right)+K_P\omega_0^2+\frac{2K_R}{T}\left(\frac{1-z^{-1}}{1+z^{-1}}\right)}{\frac{4\left(1-2z^{-1}+z^{-2}\right)+T^2\omega_0^2(1+2z^{-1}+z^{-2})}{T^2(1+2z^{-1}+z^{-2})}} \tag{2}$$

For simplicity, some adjustments are made so that the transfer function be as below:

$$G_{PR}(z) = \frac{\left(4K_P+K_P\omega_0^2T^2+2K_RT\right)+\left(2K_P\omega_0^2T^2-8K_P\right)z^{-1}+(4K_P+K_P\omega_0^2T^2-2K_RT)z^{-2}}{\left(4+T^2\omega_0^2\right)+\left(2T^2\omega_0^2-8\right)z^{-1}+(4+T^2\omega_0^2)z^{-2}} \tag{3}$$

By dividing the nominator and the denominator in Equation 3 above with $(4 + T^2\omega_0^2)$, the discrete form becomes:

$$G_{PR}(z) = \frac{\frac{\left(4K_P+K_P\omega_0^2T^2+2K_RT\right)}{(4+T^2\omega_0^2)}+\frac{\left(2K_P\omega_0^2T^2-8K_P\right)}{(4+T^2\omega_0^2)}z^{-1}+\frac{(4K_P+K_P\omega_0^2T^2-2K_RT)}{(4+T^2\omega_0^2)}z^{-2}}{1+\frac{(2T^2\omega_0^2-8)}{(4+T^2\omega_0^2)}z^{-1}+z^{-2}} \tag{4}$$

Again, for simplification, the transfer function is re-written as:

$$G_{PR}(z) = \frac{b_o+b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \tag{5}$$

where;

$$b_o = \frac{\left(4K_P+K_P\omega_0^2T^2+2K_RT\right)}{(4+T^2\omega_0^2)}$$

$$b_1 = \frac{\left(2K_P\omega_0^2T^2-8K_P\right)}{(4+T^2\omega_0^2)}$$

$$b_2 = \frac{(4K_P+K_P\omega_0^2T^2-2K_RT)}{(4+T^2\omega_0^2)}$$

$$a_1 = \frac{\left(2T^2\omega_0^2-8\right)}{(4+T^2\omega_0^2)}$$

$$a_2 = 1$$

K_P and K_R is the proportional gain and the resonance gain, T is the sampling time and $\omega_o$is the fundamental frequency of the system in rad/sec. The steady state error of the system is nearly eliminated with the resonance part added to the proportional controller. By substituting T with 50µs and $\omega_o$with 2π x 50 Hz, and by trial and error tuning, the optimum proportional and resonance gains of the PR current controller technique can be achieved. Figure 1 shows the snapshot of PR block diagram in Matlab Simulink.

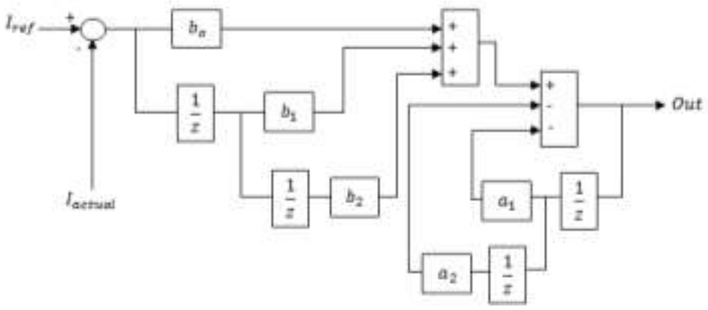


Figure 1. A proportional resonance (PR) current controller block diagram

2.2. Randomized PR control method

Instead of using a fixed proportional gain, $K_{P,}$ a random signal is added to generate a new randomly varying proportional signal for the controller. This method affected the overall harmonic orders that will result in further reduction of the grid current THD both on single inverter system and parallel inverter system. Based on (Equation 5), the discrete transfer function of the randomized PR current controller becomes;

$$G_{PRrandomized}(z) = \frac{b_o+b_1z^{-1}+b_2z^{-2}}{1+a_1z^{-1}+a_2z^{-2}} \tag{6}$$

In (Equation 6), modification is made to b_o, b_1, and b_2 where;

$$b_o = \frac{(4R_{KP}+R_{KP}\omega_0^2T^2+2K_RT)}{(4+T^2\omega_0^2)}$$

$$b_1 = \frac{(2R_{KP}\omega_0^2T^2-8R_{KP})}{(4+T^2\omega_0^2)}$$

$$b_2 = \frac{(4R_{KP}+R_{KP}\omega_0^2T^2-2K_RT)}{(4+T^2\omega_0^2)}$$

a_1 and a_2 remains unchanged thus the values for them are similar to the values obtained for the proportional resonance control method. A limit need to be set for both upper and lower value of the randomized proportional gain, R_{KP}, in order to maintain the stability of the output current result. This limitation is obtained by trial and error tuning. The edge where the output current starting unstable is taken as the upper and lower limit for the randomized proportional gain, R_{KP}. With the random gain applied, the output current is expected to maintain its shape and stability while at the same time its harmonic spectrum will reduce the THD.

3. EXPERIMENTAL RESULTS AND ANALYSIS

In this section, results for the parallel inverter system are shown and analysed and divided into two sub sections. Sub section 1 discussed on parallel system using conventional PR method and sub section 2 discussed on parallel system using randomized PR method. Initially, each of the inverters is set up independently as a single grid connected unit before they are connected in parallel at a point of common coupling. The inverter operates from a $50V_{DC}$ bus, connected to a $20V_{AC}$ grid voltage. Most important thing is each of them is synchronized to the supply network through its own Zero Crossing Detector unit. The harmonic profiles are collected using a Yokogawa power analyser which has been set up to be acquiring over 16 fundamental current cycles. The controller parameters are tuned independently by software to achieve the best possible output. Besides that, each of them is controlled so that it works at unity power factor. The harmonic spectrum of each inverter is recorded at three separate intervals and the average harmonic spectrum is calculated as a measure of inverter performance. This is done to evaluate the average performance of the inverter over time. All datas is imported into Excel in order to present them in graphical format. Figure 2 shows the diagram of two inverter units connected in parallel and supply the grid.

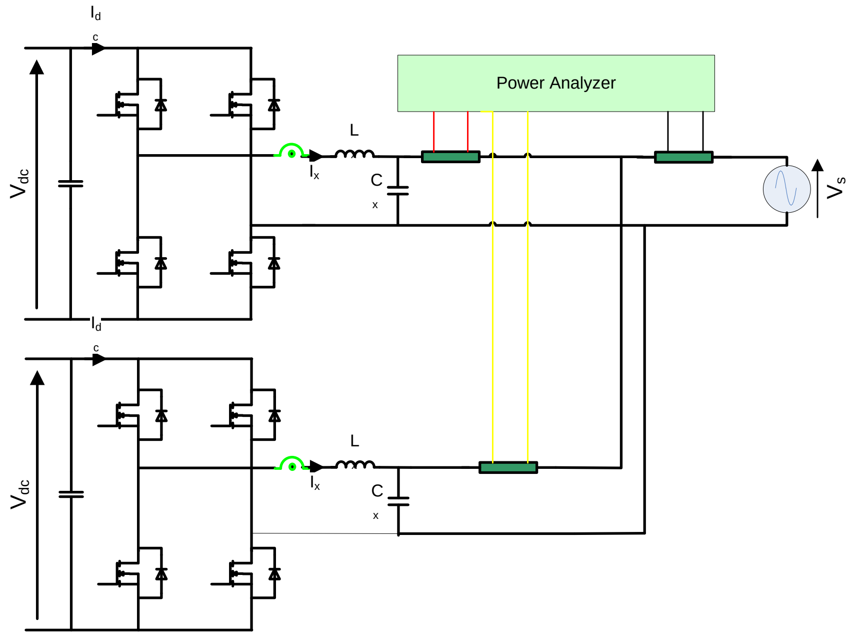
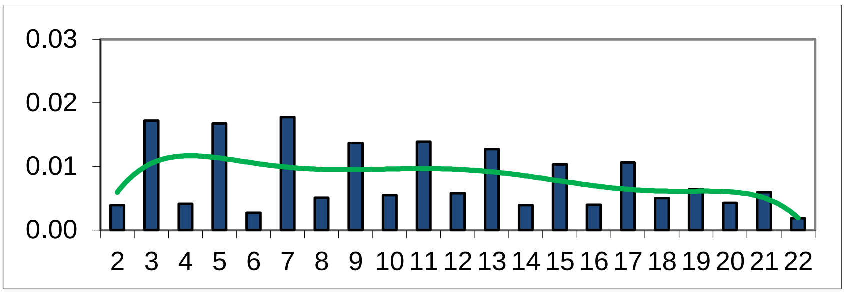


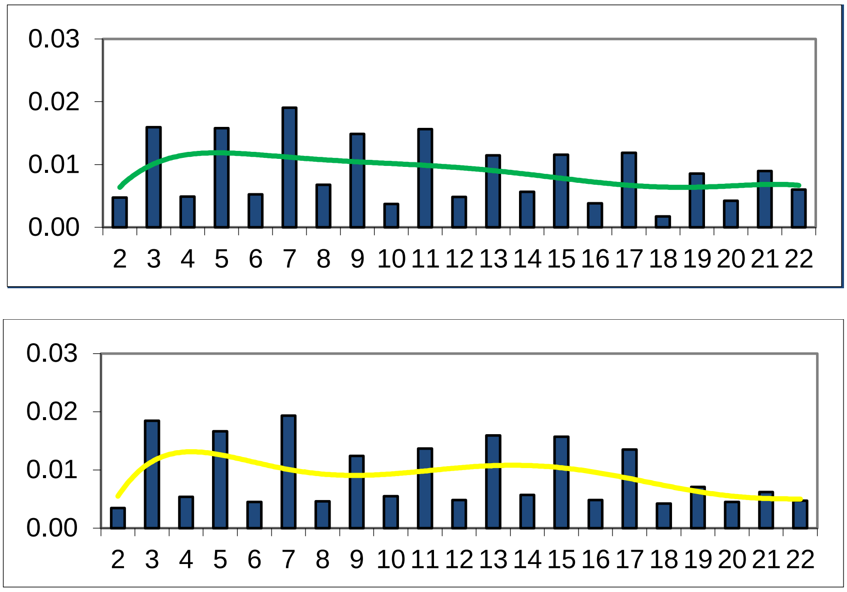
Figure 2. Parallel connected inverter system

3.1. Experimental results with PR current control technique

Here, performance of parallel inverter system when operated with PR controller is analysed. Current measurements are through the power analyser at the output of each inverter. For overall current performance, an additional current measurement is taken at the point of common coupling. Figure shows the harmonic performance of the inverters. Three sets of data are collected and the average is determined for each inverter.

Based on the Figure 3, it can be seen that about the same trendline is occurring in inverter 1 and 2 harmonic profiles. In particular, it is observed that the highest distorted component are at the 3rd, 5th, 7th, 9th harmonic. When connected in parallel, harmonics addition and similar characteristics are observed. Table shows the recorded THD value for each inverter as well as the resultant output current THD for the parallel system.





Trace A Inverter 1, harmonic spectrum of inverter output current
Trace B Inverter 2, harmonic spectrum of inverter output current
Trace C Harmonic spectrum of parallel inverter system output current

Figure 3. Harmonic spectrum of inverters when using the PR control

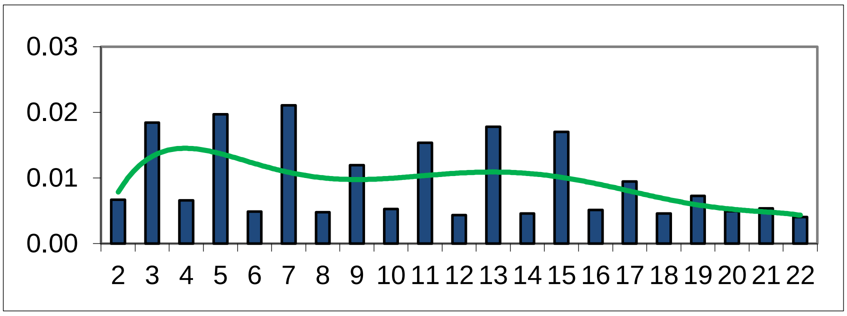
Table 1. THD value of two inverter system connected in parallel using conventional PR control

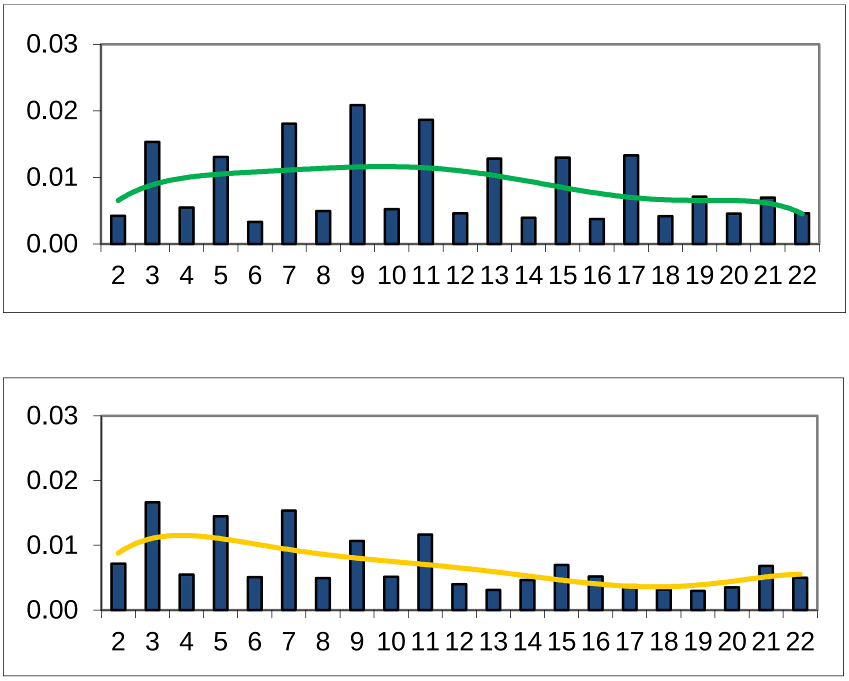
THD inverter 1	THD inverter 2	THD system output
4.98%	5.14%	5.06%

By looking at the values in Table 1, a comparable THD value is observed at the point of common coupling that is around 5%.

3.2. Experimental results with randomized PR current control method

Here, the same circuit topology is used but with modified control mode. Other than using fixed gain, the gain in tuned randomly within a specified range. Again, three sets of data are collected and the average is taken for each inverter. The average harmonic performance for the inverters are as in Figure 4. Table 2 shows the recorded THD value of each inverter and resultant THD value of the system output.





Trace A Inverter 1, harmonic spectrum of inverter output current
Trace B Inverter 2, harmonic spectrum of inverter output current
Trace C Harmonic spectrum of parallel inverter system output current

Figure 4. Harmonic performance for Inverter 1, Inverter 2 and both inverters operating in parallel

Table 2. THD value of two inverter system connected in parallel using randomized PR control

THD inverter 1	THD inverter 2	THD system output
4.88%	5.02%	4.34%

Results from Figure 4 and Table 2 above confirm that it is possible to tune the harmonic performance of each inverter unit by tuning the PR controller randomly. It can be observed from Figure 4 that the profile trendline of each inverter unit is now being dynamically varies with time, affected the harmonic profiles and thus reduce the system output THD value to further below 5%, to 4.34%.

4. CONCLUSION

Several inverters connected in parallel and feed the supply grid has been very common topology nowadays. This paper discussed on two grid connected, parallel inverters using PR current controller technique and the modification made to improve the technique. The improvement of the controller is by tuning the controller gains randomly instead of using fixed gain at all time. Results show that, on average, the output current THD of parallel inverter system is lower when using the randomized PR control technique. When the controller gain is randomly tuned, the harmonic spectrums trendline of each inverter is likely to differ from the other inverters. This provides opportunities for harmonic cancellation in overall system output, and thus reduces the THD further down under. It is believed that this randomized technique is the first one applied to the PR current control method. Looking at the current increasing trend of using several renewable technologies and feed the grid, this new approach of controller is expected to improve the harmonic profiles and further reduced the grid current THD value.

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REFERENCES

[1] D. Chen and L. Xu, *"DC Microgrid with Variable Generations and Energy Storage*," Renewable Power Generation, IET Conference, pp. 1-6, 2011.
[2] B. Williams, *et al.,* "*Using Microgrids to Integrate Distributed Renewables into the Grid,"* Innovative Smart Grid Technologies Conference Europe, pp. 1-5, 2010.
[3] K. S. K, *et al*, "*Power Quality in Grid Connected Renewable Energy Systems: Role of Custom Power Devices,"* International Conference on Renewable Energies and Power Quality, 2010.
[4] M. Calais, *et al*, "*Inverters for Single Phase Grid Connected Photovoltaic System-an Overview*," Power Electronics Specialists Conference, pp. 1995-2000, 2002.
[5] M. Armstrong, *et al*, "Low Order Harmonic Cancellation in a Grid Connected Multiple Inverter System via Current Control Parameter Randomization," *IEEE Transactions on Power Electronics*, vol. 20, pp. 885-892, 2005.
[6] "IEEE Recommended Practice for Utility Interface of Photovoltaic (PV) Systems," *IEEE Std 929-2000*, 2000.
[7] S. A. Lakshmanan, *et al*, "*A Novel Current Controlled SVPWM Technique for Grid Connected Solar PV System,"* IEEE PES General Meeting, Conference and Exposition, pp. 1-5, 2014.
[8] T. Liu, *et al*, "*A Novel Current Dual-Loop Control Strategy for Three Phase Grid-connected VSI with LCL Filter,"* Power Electronics and Motion Control Conference, vol. 1, pp. 626-630, 2012.
[9] R. Teodorescu, *et al*, *"A New Control Structure for Grid Connected LCL PV Inverters with Zero Steady-state Error and Selective Harmonic Compensation,"* Applied Power Electronics Conference and Exposition, vol. 1, pp. 580-586, 2004.
[10] P. Mattavelli and F. P. Marafao, "Repetitive-based Control for Selective Harmonic Compensation in Active Power Filters," *IEEE Trans. Ind. Electron*, vol/issue: 51(5), pp. 1018-1024, 2004.
[11] R. C. Costello, *et al*, "Odd Harmonics Digital Repetitive Control of a Single-phase Current Active Filter," *IEEE Trans. Power Electron*, vol/issue: 19(4), pp. 1060-1068, 2004.
[12] S. Jiang, *et al*, "Low THD, Fast Transient and Cost Effective Synchronous-frame Repetitive Controller for Three Phase UPS inverters," *IEEE Trans. Power Electron*, vol/issue: 27(6), pp. 2994-3005, 2012.
[13] J. M. Olm, *et al*, "Stability Analysis of Digital Repetitrive Control Systems under Time Varying Sampling Period," *IET Control Theory Application*, vol/issue: 5(1), pp. 29-37, 2011.
[14] R. Teoderescu, *et al*. "*Proportional-resonant Controllers and Filters for Grid Voltage-source Converters,"* Electric Power Applications, IEE Proceedings, vol. 153, pp. 750-762, 2006.

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