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Randomized Integral Gain of Pi Current Controller for A Single Pv Inverter System

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ABSTRACT

This paper is concerned with the problem of network power quality when grid connected systems are used to feed the grid. These systems use power electronic components such as inverters that produce harmonics which adversely affect the power quality of the distribution network. Instead of using a conventional PI current controller with a fixed proportional and integral gain, development of new control method is considered to overcome the total harmonic emissions in PV inverters. It considers a modification to the controller where a random integral gain is used in the system. Experimental hardware is developed and result shows a reduced total harmonic distortion (THD) of the output current when tested with a resistive load.

Keywords: Total Harmonic Distortion; Single Inverter; Current Controller

1. Introduction

In recent years, as technology has improved, distributed generators from solar have become more popular and have been increasingly used as an alternative to coal, gas and oil. Besides its cleanest energy source, solar is also well known as the renewable energy that can always be relied on to continuously supplying electricity and meets users demand.

Figure 1 illustrates the basic concept of single PV grid connected inverter. It typically consists of a PV array, DC-DC boost converter, DC-AC inverter, a filter, and the grid. A 50Hz isolation transformer is normally used between the filter and the grid to ensure galvanic isolation between the grid and the PV system as well as to guarantee zero DC current injection into the network.

Much research on PV system has been done to investigate its efficiency. Often, grid connected inverters produce harmonics which can exceed power quality standards. The various types of harmonics are often being categorised as switching harmonics [1], low order harmonics [1], and DC current injection [2]. A.Testa et.al [3] also demonstrated that inter-harmonics and sub-harmonics are an additional source of harmonic pollution which may need to be considered. Switching harmonics are the high order harmonics generally in kHz range generated due to the high frequency of inverter switching whilst the deficiencies in the inverter current controller are being the cause of low order harmonics generation typically at integer multiples closer to fundamental frequency. The

causes of DC current injections have been observed simply from the imperfect inverters that do not completely invert all DC components to AC. Inter-harmonics at the other hand occur at the frequencies that are not fixed at integral multiples of fundamental. Their frequencies are variable and difficult to trace. These inter-harmonic components may cause sub-synchronous oscillations, voltage fluctuations and light flicker. V.E.Wagner et.al [4] has summarised the effects of harmonics on many equipments including circuit breakers, transformers, metering and lighting. In the paper, they highlighted two groups of harmonic effects; the heating effects and the disturbance in equipments operation. Subjak and Mcquilkin [5] have also analysed the causes, effects and measurements of harmonics. The paper briefly explained the definition of harmonics and how harmonics can cause communication interference, heating, as well as solid-state device malfunction.

On the other hand, a paper by H.Soo et.al [6] stated a different view about low order harmonics. It demonstrated that low order harmonics profile can actually be
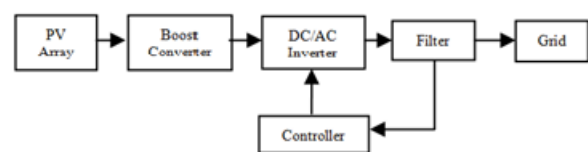
Figure 1. Basic concept of grid connected inverter.

affected when the condition of grid voltage varies due to the changes in the grid impedance and the connection of non-linear loads. Although it suggested an adaptive control algorithm in order to compensate the problems, the result is still uncertain.

To improve the harmonic performance of grid connected inverter systems, it is possible to make improvements to the power electronic converter hardware; inverter topology [7,8], PWM switching schemes [9-11], and so on. Alternatively, it is possible to enhance the performance and robustness of the current controller [1, 12-14]. This paper focuses on control methods for improving the low order harmonic performance of PV inverter systems. Literature research has shown that a number of unique control schemes have been presented, all with their associated merits and disadvantages. In this paper, a modification is made to the integral gain of the conventional PI current controller to produce a new control scheme capable of minimising the low order harmonics in the grid connected inverter systems.

The aims of this paper are:

- To demonstrate the poor low order harmonic performance of grid connected inverters using conventional PI control methods.
- To demonstrate that Control Parameter Randomisation of one of the PI gain can further improve the harmonic performance of grid connected inverters.

2. System Description

Two main parts of systems must be identify and understand first; the PWM technique and the inverter current control technique. PWM is used as a switching technique to drive the gate signals of the inverter. Whereas, the current control technique is used to response and compensate the inverter current.

2.1. PWM Switching

In this project, a unipolar PWM technique as in **Figure 2** is used as the switching technique for the H-bridge inverter. Each output from the switching scheme is fed to each of the switching devices of the inverter. It works as explained below:

If

$V_{sine} > V_{carrier}$;	Out 1 will turn on Switch 1	
$V_{sine} < V_{carrier}$	;	Out 2 will turn on Switch 2
$-V_{sine} > V_{carrier}$	;	Out 3 will turn on Switch 3
$-V_{sine} < V_{carrier}$	;	Out 4 will turn on Switch 4

Figure 3 illustrates the H-bridge inverter with Switch 1 to Switch 4 as mentioned above.
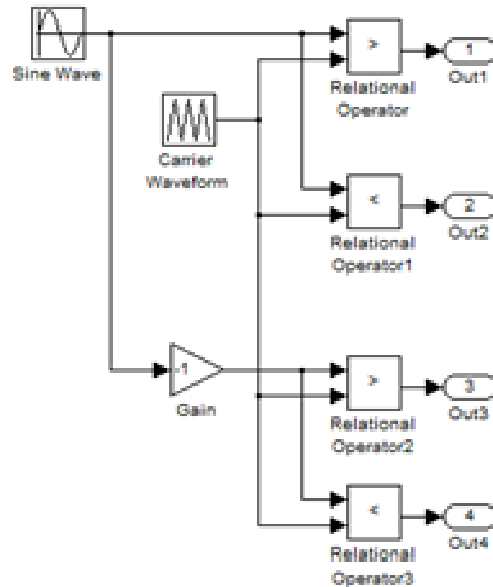
2.2. Current Controller

In this project, rather than the proportional, integral and derivative (PID) system, only the proportional (P) and integral (I) terms are used in the current controller system. This type of controller is the most common controller applied as the inverter current feedback process. The term P will give an output that is proportional to the system error which is the difference between the system output value and the desired value. It has a gain, Kp which will multiply the error and response to it. The purpose is to reduce the rise time of the system. However, using this proportional term alone will result in having a system stationary error. In order to eliminate this error and complete the P based control, the integral part is used. The output of the integral part is the multiplication of a gain, Ki and the summing of the previous errors to the current system error. This is a continuous process which will stop if the system signal or the system output value matches the desired value demanded by the user.
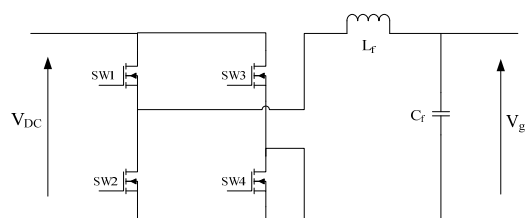
The analogue PI transfer function is

$$G_{PI}(s) = K_P + \frac{K_I}{s} \qquad (1)$$

After the conversion to the discrete domain by the method of z-transform analysis, the transfer function becomes

Figure 2. A unipolar PWM switching.

Figure 3. H-bridge inverter system.

$$G_{PI}(s) = K_P + \frac{K_I}{1 - z^{-1}} \qquad (2)$$

Figure 4 below illustrates the PI current controller block diagram. The system measured current is compared to the reference current and will be used in the controlling process. The output signal after the process has been taken is then used for the PWM inverter switching.

In order to realize the second aim of this paper, a modification needs to be made to the controller system above. It considers a random integral gain, R_{KI} to replace a fixed integral gain, K_1 to the controller system. It means that the tuning of the integral is adjusted randomly and yields an output harmonic spectrum that changes over time. This is done by adding a random number to the integral gain of the controller system and becomes a newly randomized PI controller system as in **Figure 5**. The transfer function of the new randomized PI controller is

$$G_{PI}(s) = K_P + \frac{R_{KI}}{1 - z^{-1}} \qquad (3)$$

3. Experimental Setup

An experimental setup using a DC supply voltage of 30V and an approximate 5 Ohms resistive load is built as depicted in figure below. **Figure 6** shows the experimental test setup for the system. This system consists of a single 45W prototype full bridge inverter with an LC filter having a cut off frequency of 2 kHz. This cut off frequency is about one over tenth of the sampling frequency which is an acceptable value. Besides the inverter and the filter, a TMS320F2812 digital signal processor (DSP) is
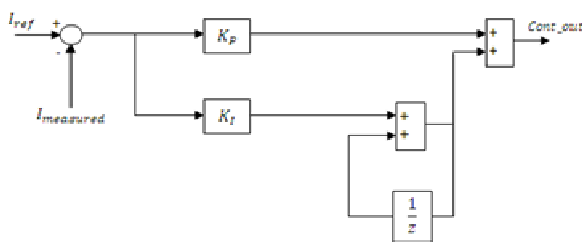
Figure 4. Block diagram of PI current controller.
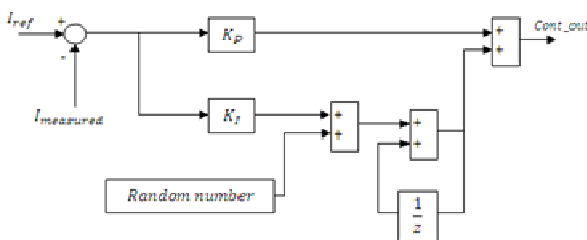
Figure 5. Block diagram of randomized integral gain of PI current controller.

also used to program and run the system. The output current of the system is sensed using a current measurement board which consists a current sensor and is fed to this DSP as the measured current. The current demand is set to 3A and the DSP will then performed the controlling process as well as the PWM switching. It then sent the outputs to the inverter system. Harmonic data spectrum of the output current is measured using a power analyzer which will calculate the THD and display the data up to the 50th harmonic orders. The analyzer is set so that the data displayed is an averaged data taken over 16 fundamental current cycles.

4. Results and Discussion

After trial and error tuning, the chosen value for K_P and K_1 is 2 and 0.35 respectively. Four sets of data readings are captured from the power analyzer and they are transferred to Excel for further analysis. An average reading is then calculated and results are displayed as figures next.

For the conventional PI current controller, the harmonic data as in **Figure 7** shows a THD of 5.65% with high magnitudes on the 2nd to the 11th harmonic orders. This is higher than the limit set under the IEEE 519-1992

**Figure 6. Experimental test setup for inverter system.**
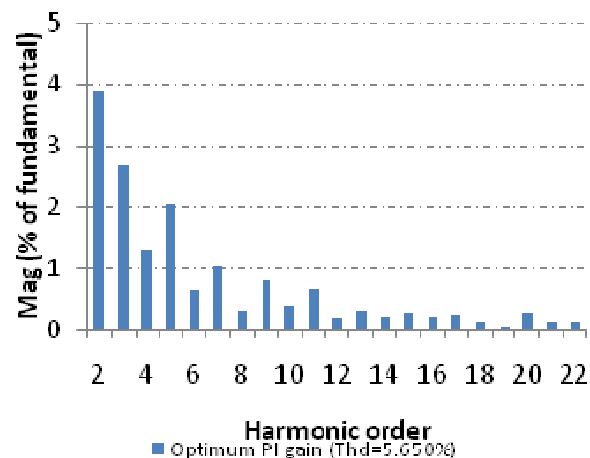
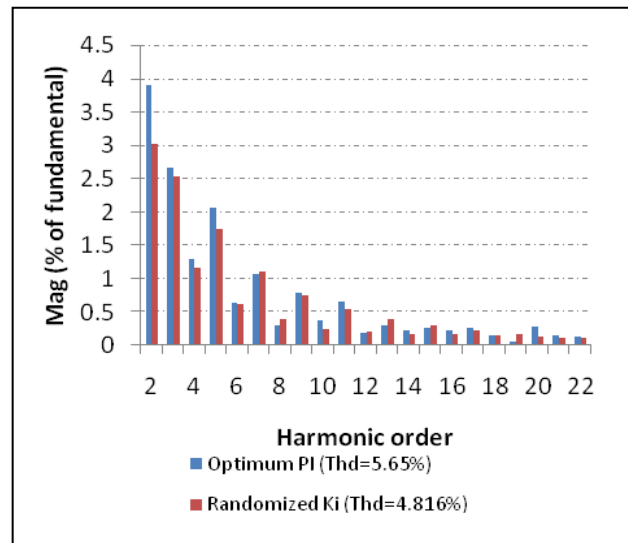**Figure 7. Harmonic spectrum of PI current controller.**

which is 5% for the overall THD [15]. In order to improve the spectrum thus reduces the overall output current THD, a random signal is added to the integral gain of the PI controller above. This random signal is generated using the software and is limited to a certain range so that the output current instability is prevented. The range of the signal is determined by testing the inverter system with different values of K_1 gain. The maximum and minimum gain value before the output current becomes unstable is then chosed as the random signal limit. When this limit is added to the integral gain, K_1, a new randomized gain, R_{K1} is then randomly adjusted and varied between 0.2 to 0.5 whilst the proportional gain, K_P remain fixed with the value of 2. A simple digital low pass RC filter is also added after the random number generation to smooth the variation signal. This filter has a cut off frequency of approximately 560Hz. It is observed during the experiment that higher cut off frequency will not make the random signal any smoother and lower cut off frequency will limit the range of the random signal. **Figure 8** below shows the waveforms of the random signal before and after filtering.

(a)

(b)
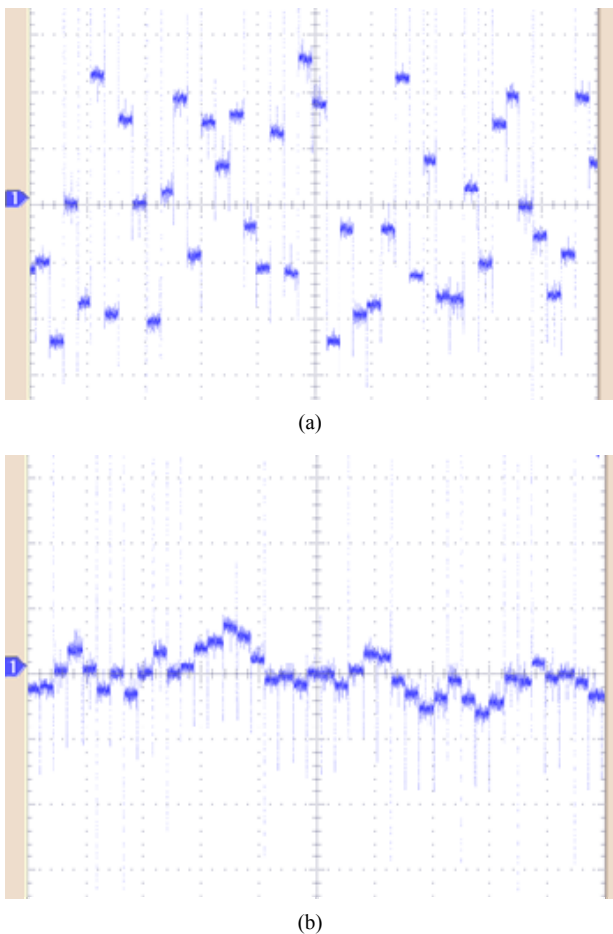
Figure 8. Random signal generation (a) before filtering; (b) after filtering.
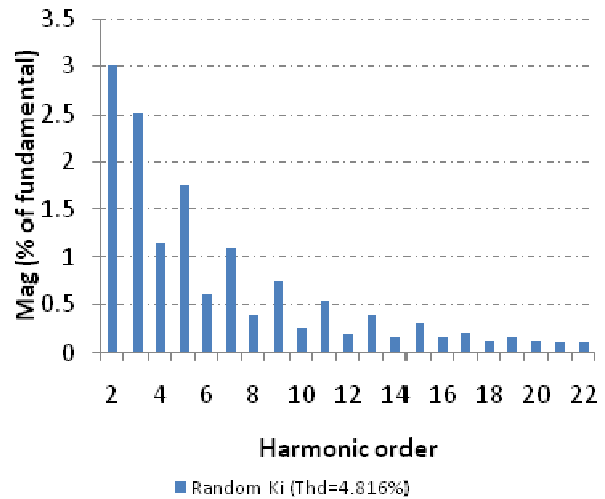
Figure 9. Harmonic spectrum of randomized integral PI current controller.

Figure 10. Harmonic spectrum comparison.

The following figures are the output current harmonic spectrum of the randomized integral PI controller and the comparison between the conventional PI and the randomized integral PI controller.

From **Figure 9**, it can be seen that the THD is reduced to 4.816% which is about 15% reduction from the system when using the conventional PI current controller. This THD value is a satisfied value under the IEEE 929-1992 as mentioned before. Comparison of the harmonic spectrum between the two output results can be seen from **Figure 10**. Based on the figure, the trends for both spectrums are different where a reduction or increment of individual harmonic orders is observed. Most importantly, the magnitude of the lower order harmonics that is from the 2nd to the 11th harmonic orders are mostly decreased except for the 7th and 8th orders which have a small in-

crement. Harmonic orders beyond the 11th show a fair reduction as well as increment. This behaviour of having a reduction and increment in harmonic orders magnitude yields to the reduction of the Total Harmonic Distortion (THD) of inverter system when using the proposed method.

5. Conclusions

This paper has proposed a modified PI current controller to overcome the issue of higher THD in a single inverter system when using the conventional PI current controller. This modification includes the integral gain, K_1 of the PI controller to be adjusted automatically using the randomized integral gain, R_{K1} whilst the proportional gain, K_P of the controller remain the same. Experimental results show an improved THD performance by 15% compared to the system when using the conventional PI method. With no further components are required in order to implement the proposed method, the total cost of the PV inverter system remains unchanged.

6. Acknowledgements

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