# Current control loop of 3-phase grid-connected inverter

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# Current control loop of 3-phase grid-connected inverter

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**Abstract**. This paper presents a comparative study of current control loop in 3-phase inverter which is used to control the active and reactive output power.  Generally, current control loop, power control loop and phase lock-loop are the conventional parameters that can be found in an inverter system controlled by the conventional linear control type, for instance proportional (P), integral (I) and derivative (D). If the grid remains stable throughout the day, PID control can be use. However variation of magnitude, frequency, voltage dips, transient, and other related power quality issues occur in a 3-phase grid often affects the control loop. This paper aims to provide an overall review on the available current control techniques used in grid connected system.

## 1. Introduction

Fossil fuels are non-renewable energy resource because they take millions of years to generate. As the amounts of fossil fuel used are more than the ones produced, it is expected that one day all the reserves fuels will be depleted [1]. In respond to this, the Malaysian government has shown interest in green energy developments and aims to ensure 11% of the country's total energy capacity is powered using renewable energy by 2020 [2]. A positive outcome especially to the environment is expected as 42.2 million tons of carbon emission will be eliminated with addition of generating more job opportunities [3]. By the year 2020, it is anticipated that addition 10.8-gigawatts of electricity will be needed in the country [4]. An ongoing research is being conducted on renewable energy sources such as solar, wind and biomass to ensure safe, cheap and reliable energy sources to replace fossil fuel. Among all, production of electrical energy from renewable sources in photovoltaic (PV) and wind-energy has been given wide attention. To avoid expensive cost on storage devices, researchers have considered implementing these renewable energy sources into the grid which is called grid-tie system.

## 2. Current control techniques

Control scheme such as PID, hysteresis free running and Dead Beat control has been used in the current control loop for the past decade. Current loop controls are robust as their insensitive characteristics towards electrical noise. A current controller operates by generating signals for the pulse width modulation so it produces a switching state according to the desired reference point. Figure 1 shows an example of an inverter using a simple current controller scheme.
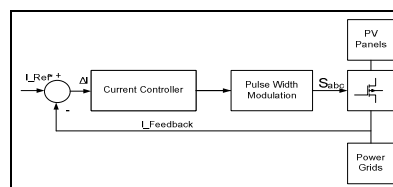


**Figure 1.** Basic block diagram of current control PWM inverter

The current error ΔI will decrease over time as the output current reaches the desired reference current. Designing an error compensator within the current control must be taken into consideration as it affects the system stability, transient respond and dynamic behavior [5] [6]. Controlling the output current protects the inverter from overload and ensures sufficient power delivering.

Advantages of current control:

    o   Output unaffected by load parameter changes.
    o   Peak current and overload protection.
    o   Extremely good dynamics.

In grid-connected system, current controllers must be carefully design and can be unstable if the modeling does not includes nonlinearities such as switching dead time, delays and semiconductor behavior[6][7]. An adaptive control approach was proposed to overcome the model uncertainties and successful in minimizing power quality deteriorate for harmonic and unbalance output [8].

### 2.1. Deadbeat current control
Classified as predictive control group because it predicts the future behavior of the output controlled variables [9][10]. This scheme calculates the require reference voltage vector v*(k) within each sampling period k+1 such the load current i(k) will be equal to the reference current i*(k). Figure 2 shows the block diagram of deadbeat current control scheme.



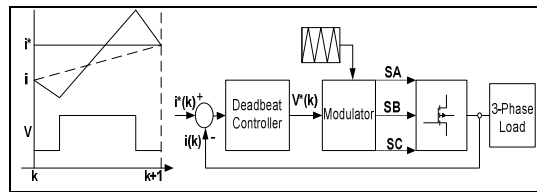**Figure 2.** Deadbeat current control and waveform operation

Advantages:
    o   Capable of having the fastest transient response.
    o   High precision in current control.

Despite its advantage and superior traits compare to conventional methods. Research has discovered two main practical issues related to deadbeat control [10][11][12]:
    o   Bandwidth limitation due to the inherent plant delay.
    o   Sensitivity to plant uncertainties.

Ideally to obtain zero reference error, all the plant definite parameters must be known to achieve zero time delay response. Changes in the plant parameter due to resonance at output filter (LC or LCL) will make the preset controller gain not able to achieve deadbeat response. Figure 3 shows the pole placement of different resistance value from no load to infinite load [11].
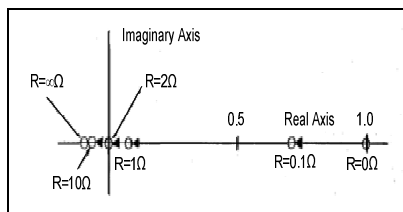


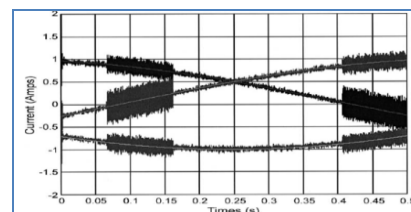**Figure 3.** Reference signal waveform



**Figure 4.** Zero current clamped oscillation [13]

To eliminate plant uncertainties in deadbeat control, an integral compensator was proposed to compensate the inaccurate plant model and variation of DC voltage source [8]. As the output performance is acceptable, the performance of PI controller is inadequate against nonlinearities and dynamics of grid system. Another problem associated to deadbeat control is zero current oscillation, this happens if the measured phase current crosses zero during dead time. Figure 4 shows the waveform of zero current oscillation measured from output current. An improved predictive current regulation (PCR) was introduced [10] [13], this technique further increases the system robustness to load parameter mismatch and was able to reduce zero current clamped oscillation.

### 2.2. Hysteresis current control
Free-running hysteresis has been used in variable speed ac-drives, active power filters (APF) [10], power factor correction (PFC) [11] and multilevel inverters [12]. It operates by making the output ia, ib, ic close to the desired reference current ia*, ib*, ic* within a hysteresis band as shown in figure 5.
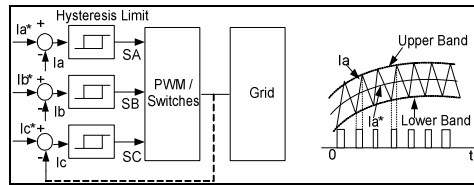
**Figure 5.** Hysteresis current control
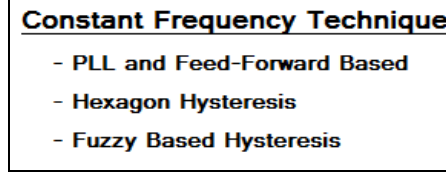


**Figure 6.** Fix frequency hysteresis current control

The advantages of hysteresis current control:
o   Simple implementation.
o   Good stability and dynamic performance.
o   Independence of load parameter changes.

Having three separate hysteresis control, each signal SA, SB, SC will produce switching states independently to maintain it's current within the hysteresis limit. Due to coupling effect, the performance at zero-crossing deteriorates and has related issue in variable switching frequency [10].

Disadvantages:
o   High current ripple
o   Injecting high frequency components at output
o   High switching losses

Adaptive hysteresis current control was proposed to overcome the variable switching frequency.  This technique enables the limit bands to be varied according to output load hence achieving constant switching frequency and lower switching losses [13][14][15]. The types of adaptive hysteresis current control is shown in figure 6 Implementation of hexagon based control was done in synchronous rotating d-q coordinates [16][17]. The entire current error is maintained within a hexagon area like shape which rotates about the reference current as shown in figure 7  Selection of zero-voltage vectors reduces the switching frequency and eliminates the interaction of coupling effect [10][18].
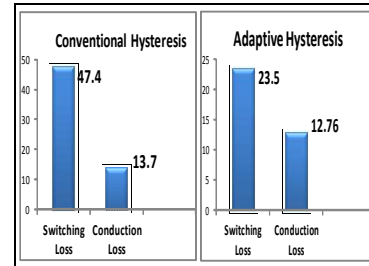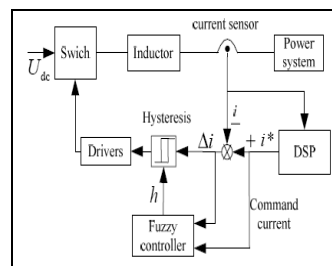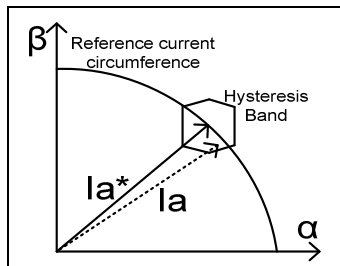


**Figure 7.** Hexagon switching



**Figure 8.** Fuzzy based control [10]



**Figure 9.** Losses comparison [13]

An intelligent control such as fuzzy based in adaptive hysteresis control is shown in figure 8 [10]. With fuzzy logic controller, transient overshoots and tracking error was improve significantly and increase the robustness of overall system [7]. Comparisons between conventional and adaptive hysteresis current control method has been done on a 1650-watts HERIC "High efficient and reliable inverter concept" [13]. As shown in figure 9  adaptive hysteresis has smaller values in switching and conduction loss. Although overall efficiency between the two methods are small which is 96.2% for conventional and 97.6% for adaptive, this experiment was conducted on a single-phase six switch inverter. This method is suitable for topology that has more switches such as multilevel inverter.

*2.3. Comparison study*
Comparison of current control loop on a grid connected system was conducted using matlab-simulink. The inverter parameters are shown in table 1.

| DC voltage | 1200V |
|---|---|
| Frequency | 50Hz |
| LC Filter | L=7.5mH , C=1.2mF |
| Load | 415V, 45kW , +1kVAR |
| **Current Control Methods** | |
| Conventional PID | SVPWM ,Fs=2000Hz |
| PID - Decoupling | SVPWM ,Fs=2000Hz |
| Hysteresis | PWM |
| Deadbeat | PWM |

**Table 1.** Inverter specification
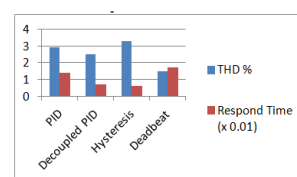


F**igure 10.** THD and respond time comparisons

A comparison of THD and respond time of the current control technique is shown in figure 10. It is observed that hysteresis current control has the highest THD with 3.3% but opportunely has the fastest respond time with 6ms. Deadbeat control has the smallest THD with 1.57% but has slowest respond time with 17.5ms. For the conventional PID and decoupled PID, an improvement is seen for the decoupled PID with THD of 2.5% compared to 2.98% and respond time 7ms compared to 14ms.

### 3.0. Conclusion

This paper has presented a general review of current control techniques used in grid connected system with the general problems associated to each methods. Improvement approach was also presented. It is concluded that comprehensive study and analysis on current control loop must be conducted to ensure safe, reliable and optimum performances in renewable system since the performance is largely correlated to the quality of the current control loop. Further improvements to the current loop can be made by using complex computation techniques such as fuzzy and neural network control schemes.

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