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# Efficient Deadbeat Control of Single-Phase Inverter with Observer for High Performance Applications

***Abstract*** *In this paper, a deadbeat control technique for single-phase inverters used in UPS applications is presented. For the suggested control approach to maintain sinusoidal output voltage for high dynamic performance even with load fluctuations, measurements of capacitor current and output voltage are necessary. By reducing the error between the output voltage and the voltage reference without adding more current sensors, the deadbeat controller improves the performance of the proposed controller. It also reduces load voltage distortion and restores the system state in the event of an external shutdown-loop road interference. We suggest a capacitor current estimation based on the Luenberger observer to address this flaw. PROCESSOR-IN-THE-LOOP The "P.I.L" test method, which can be thought of as an expensive system, enables us to create and evaluate controllers by running built-in C code on the DSP scheduled for the controller during simulated PSIM power phase control. To address this drawback, we propose a capacitor current estimation based on the Luenberger observer.*

***Streszczenie.*** *W artykule przedstawiono algorytm sterowania martwym uderzeniem falowników jednofazowych do zastosowań w systemach zasilania awaryjnego (UPS). Proponowana metoda sterowania wymaga pomiaru prądu kondensatora i napięcia wyjściowego w celu utrzymania sinusoidalnego napięcia wyjściowego w celu uzyskania wysokiej wydajności dynamicznej nawet przy zmianach obciążenia. liczbę czujników prądu, a także eliminuje zniekształcenia napięcia obciążenia i przywraca stan systemu w przypadku zewnętrznej ingerencji w pętlę wyłączania drogowego. Aby rozwiązać ten problem, proponujemy oszacowanie prądu kondensatora na podstawie obserwatora Luenbergera. PROCESOR-W-PĘTLI „P.I.L" to metoda testowa, która pozwala nam tworzyć i oceniać kontrolery poprzez uruchomienie wbudowanego kodu C na DSP zaplanowanym dla kontrolera podczas symulowanej kontroli fazy mocy PSIM, co można uznać za kosztowny system , aby poradzić sobie z tą wadą, proponujemy oszacowanie prądu kondensatora na podstawie obserwatora Luenbergera. (**Wydajna kontrola martwego rytmu falownika jednofazowego z obserwatorem do zastosowań o wysokiej wydajności**)*

**Keywords**: deadbeat control, single-phase inverter, PWM, Luenberger observer, P.I.L, DSP, CCS.
**Słowa kluczowe:** sterowanie martwe, falownik jednofazowy, PWM, obserwator Luenberger, P.I.L, DSP, CCS.

## 1. Introduction

In some situations when a high-quality voltage is required, controlling the inverters with the output LC filter is crucial. Uninterruptible power supplies (UPS), distributed generation, and island applications based on renewable energy sources are some of these uses. [1, 3] Deadbeat control is a control strategy that has been developed to achieve fast and accurate response to changes in the reference signal, and to ensure robustness against system disturbances and uncertainties. The deadbeat control strategy is based on the state-space representation of the inverter, which is a mathematical model that describes the behavior of the system as a set of differential equations. Backup mode and bypass mode are the two operational modes of any UPS system. The two modes, including deadbeat controller, are shown in [6, 9], and a UPS should be able to generate a regulated sinusoidal output voltage with low total harmonic distortion (THD) in both of these modes. DSP employs the majority of the approaches. The disturbance observer and deadbeat controller are employed in [5,10] to ensure proper response and reliable controlled performance. The PWM pattern in the presence of load uncertainty is not specified, however a viable PWM technique employing a modified deadbeat controller is explicitly explained [11, 12]. Deadbeat control for power converters using fractional-order delay compensation is defined as an efficient and potent delay compensation approach in [13] and has been applied in various control systems. In [14], a single-phase inverter's deadbeat-based proportional-integral (PI) controller is also described with a comparison to conventional control techniques. However, the implementation of the deadbeat controller in this technique is very difficult; the deadbeat controller in this technique has been widely used.

The major goal of the control is to produce an output voltage that is approximately sinusoidal across the LC filter's output capacitor. Because it can reduce errors between the reference and measured values as long as the number of samples goes to infinity and the error so far to zero, deadbeat control is the most alluring control method in discrete-time and gives the inverter a quick dynamic response. The total harmonic distortion (THD), which determines the inverter's output voltage, is extremely low. Even when the load fluctuates, deadbeat control is sensitive to the modification of the filter parameters; this demonstrates that the suggested deadbeat control system can function steadily as long as the load variation is within the acceptable range. An observer to gauge capacitor current is suggested in order to reduce the number of sensors.

However, traditional deadbeat controllers experience two delays: the first occurs when the PSIM simulates the algorithm after CCS builds and installs it on a DSP-based platform, and the second occurs because of a steady-state error that is inherent to the deadbeat control algorithm [11]. It affects the stability of the system and results in ripples and phase shifts in the output current.

The paper is structured as follows: An overview of the deadbeat controller is provided in Section II, and the deadbeat control formulations are provided in Section III. Section V presents the results of the simulation of the control deadbeat without and with an observer, Section VI presents the experiment with the processor in the loop P.I.L in carte DSP, Section IV describes the design of the observer Luemberger, and Section VII provides a conclusion and a possible direction for future research.

## 2. description of system

Figure 1 illustrates the proposed single-phase inverter, which is composed of an H-bridge inverter interconnected to the load via LC filtering. In order to carry off energy transfer and power conversion, switching devices called insulated gate bipolar transistors (IGBTs) are used. Before the load, higher harmonics are filtered using LC filters. The observer Luemberger produces the current and voltage in the capacitor. With regard to operating conditions, this system is more versatile and operates better with unbalanced loads.

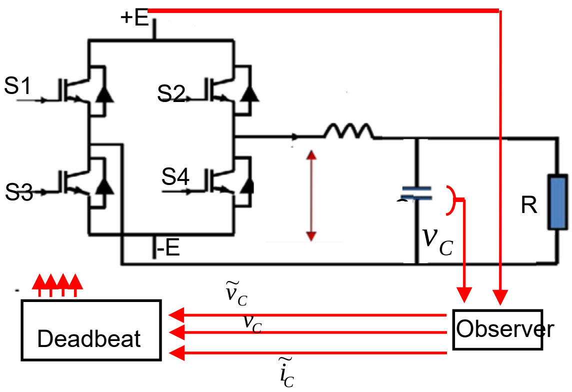



Fig. 1. Basic scheme of the proposed system.

### 3. Considered system

Two arms in half-bridge make up the single-phase inverter. The source-inverter-filter-charge system is represented by the second-order linear model of the following diagram if the power switches S1 and S'1 are assumed to be ideal (and insignificant).

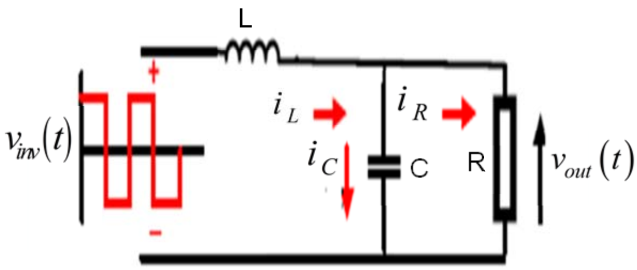



Fig. 2. Basic scheme of the proposed system.

According to figure 2 above, and using Kirchhoff's law, we obtain the following equations:

(1) $$\begin{cases} V_{inv}(t) = V_L(t) + V_C(t) \\ i_L(t) = i_C(t) + i_R(t) \end{cases}$$

The transfer function of the LC filter is given below :

(2) $$\frac{V_C(s)}{V_{inv}(s)} = \frac{1/LC}{s^2 + \frac{1}{CR}s + \frac{1}{LC}}$$

Figure (II.4) presents the Bode diagram of the transfer function $\frac{V_C}{V_{inv}}$ for different values of charge R.

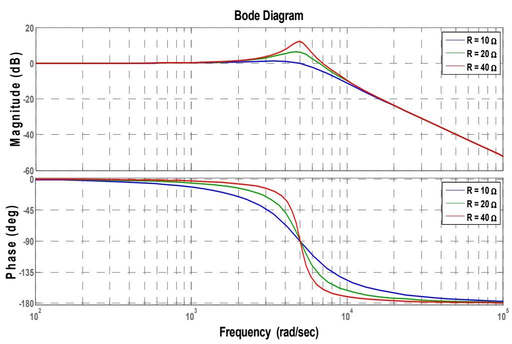



Figure 3: Bode diagrams of the transfer function with charge variation R (blue for R=10Ω, green for R=20Ω, and red for R=40Ω)

This figure proves the resonance effect at the 1 kHz frequency, which increases when the value of R is higher. Small gains and phase shifts are observed around the fundamental frequency. Moreover, a gain of -40dB is obtained at the switching frequency of the converter, equal to 10 kHz. So only the fundamental component of the voltage will pass, and the high frequencies of the harmonic content will be filtered out.

The state space representation of this system is given by:

(3) $$\dot{x}(t) = A\,x(t) + B\,u(t)$$

When

$$x(t) = \begin{bmatrix} x_1(t) \\ x_2(t) \end{bmatrix}$$

$x(t)$ Is state vector, such that:

(4) $$\begin{cases} x_1(t) = v_C(t) \\ x_2(t) = \dot{v}_C(t) \end{cases}$$

Using Kirchhoff's laws, the second-order linear model of the half-bridge inverter by calculating the matrices A and B

(5) $$v_{inv}(t) = v_L(t) + v_C(t)$$

(6) $$v_{inv}(t) = LC\,\ddot{v}_C(t) + \frac{L}{R}\dot{v}_C(t) + v_C(t)$$

By equation (4) we have:

So:

$$A = \begin{pmatrix} 0 & 1 \\ \frac{-1}{LC} & \frac{-1}{RC} \end{pmatrix} \quad \text{And} \quad B = \begin{pmatrix} 0 \\ \frac{1}{LC} \end{pmatrix}$$

The following figure shows the waveforms of $v_{inv}(t)$ during a sampling period $T_e$:

$v_{inv}(t)$ Is the output voltage of the inverter and have two values +*E* or –*E* as shown in Figure 2,

The discrete-time system equation of two-lever switching patterns is as follows [14]:

(7) $$x(t) = \exp\left[A(t-t_0)\right]x(t_0) + \int \exp\left[A(t-\tau)\right]B\,v_{\text{int}}(\tau)\,d\tau$$

Thus the discrete state equation from to t0 $t_1$ and $t_2$ $t_3$ is:

(8) $$X[(k+1)T_e] = \exp\left[AT_e\right]X(k) + \exp\left[A\frac{T_e}{2}\right]BE\Delta T(k),\; E\Delta T(k) = v_{\text{int}}(\tau)$$

We will find from the equation below the value of the duration than $\Delta T$ we must apply it at all times to generate the control signals of switches. Where $\Delta T(k)$ equals the pulse-width in the $k^{th}$ sampling interval. Assuming $T << 2\pi\sqrt{LC}$, the three exponential quantities in equation (7) are approximated using the power series expansion:

(9) $$A_k = \exp[AT] = \begin{bmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{bmatrix}$$

$$A_k = \begin{bmatrix} 1-\frac{T^2}{2LC} & T-\frac{T^2}{2RC} \\ \frac{-1}{LC}+\frac{T^2}{2RLC^2} & 1-\frac{T}{RC}+(\frac{1}{R^2C^2}+\frac{1}{LC})\frac{T^2}{2} \end{bmatrix}$$

A predictive deadbeat control approach, which predicts the control input at the $k^{th}$ sampling time using the system values at the $(k-1)^{th}$ sampling time, is therefore presented to help solve this problem. The reference output voltage of the inverter, or the PWM modulation signal, can be characterized as the sum of the real capacitor current $i_C$, the reference voltage $V_{ref}$, and the output load voltage of the inverter $V_{out}$ at the $(k-1)^{th}$ sampling period.

(10) $$X(k+1) = \begin{bmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{bmatrix} X(k) + \begin{bmatrix} g_1 \\ g_2 \end{bmatrix} E\Delta T(k)$$

The first line of the previous equation gives us the recurrent expression of the sampled output voltage, it gives:

(11) $$\Delta T = \frac{1}{g_1 E}(V_{ref}(k+1) - \varphi_{11}x_1 - \varphi_{12}x_2$$

### 4. State observer

The Luenberger observer is widely used in control systems because it is easy to implement, computationally efficient, and can provide accurate estimates of the system state even in the presence of noise and other disturbances. However, the observer requires knowledge of the system model and is sensitive to errors in the model parameters.

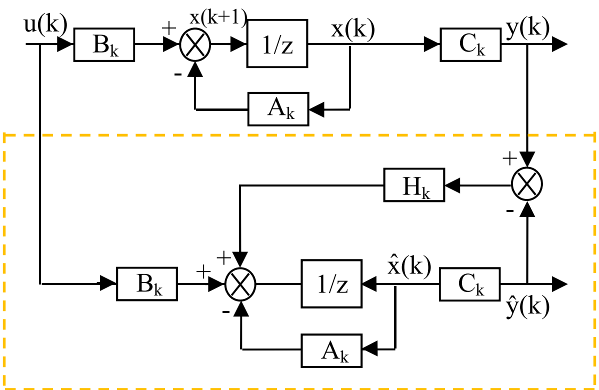



Fig.4. Diagram of observer.

A capacitor current measurement is required to determine the proposed control, and the observer principle states that by combining the feedback signal measured with knowledge-based control system components, the plant's behavior can be predicted with greater accuracy than if the feedback signal were used alone. As depicted in figure 4, the observer increases the sensor output and sends a signal of feedback to the control laws.

### 4.1State Observer Design

The system described by equation 9 must be observable in order to introduce an observer to it. In fact, the row of the observability matrix O described by must equal the number of state variables n for a system to be observable.

Observability Matrix, therefore

(12) $$O = \begin{pmatrix} C & CA \end{pmatrix}'$$

$Rang\,(O) = n = 2$, verified condition.

### 4.2. Observer Model

A discrete system's state representation is:

(13) $$SYS = \begin{cases} x(k+1) = A_k\,x(k) + B_k\,u(k) \\ y(k) = C_k\,x(k) \end{cases}$$

Where:

$$A_k = \begin{pmatrix} \varphi_{11} & \varphi_{12} \\ \varphi_{21} & \varphi_{22} \end{pmatrix},\ B_k = \begin{pmatrix} g_1 \\ g_2 \end{pmatrix}\quad C_k = \begin{pmatrix} 1 & 0 \end{pmatrix}$$

An observer with the following dynamic equation, based on Luenberger's approach, which can be written as:

(14) $$\begin{aligned} \hat{x}(k+1) &= A_k\,\hat{x}(k) + B_k\,u(k) + H_k\,(y(k) - \hat{y}(k)) \\ \hat{y}(k) &= C_k\,\hat{x}(k) \end{aligned}$$

Where: $\hat{x}(k)$ Is the estimate of the state vector; $u(k)$ : is defined as input;; $\hat{y}(k)$ : is the estimated output; $H_k$ : is the observer's gain; $e(k) = x(k) - \hat{x}(k)$

For all k-values, the error must converge to zero. When the observer error satisfies $e(k+1) = (A_k - H_k.C_k)e(k)$

So $(A_k - H_k.C_k)$ has its eigen value of $\lambda_i$ .The determinant of this matrix is this mean: $|\lambda_{i=1....n}| < 1$.

The real part should be closer to z=0 to ensure a faster real part, and the imaginary part is faster if the angle to the real axis increases, but it shouldn't be too close to the unit circle because otherwise the pole will be more resonant. These are some of the criteria for choosing the eigen values. Calculating the determinant of the matrix $(zI - A_k + H_k\,C_k)$, and by identification on the polynomial $(z-\lambda_1)(z-\lambda_2)$

We can find $h_1$ and $h_2$, so:

(15) $$\det(zI - A_k + H_k\,C_k) = (z-\lambda_1)(z-\lambda_2)$$

$H_k$ Is given by:

(16) $$H_k = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} = \begin{bmatrix} \phi_{11} + \phi_{22} - \lambda_1 - \lambda_2 \\ \frac{1}{\phi_{12}}[\lambda_1\lambda_2 + \phi_{22}(\phi_{22} - \lambda_1 - \lambda_2)] + \phi_{21} \end{bmatrix}$$

### 5. imulation study

The performance of the previously recommended control technique may be evaluated through simulations and tests utilizing the carte DSP F28335 (Digital signal processor) to integrate the control algorithm into the digital circuit and IGBT Switching devices for the single phase inverter.

The algorithm's sample period is set to 0.0001s, while the inverter's switching frequency is set to 10 kHz. The design specifications for the inverter are listed in table 1.

Table 1 Parameters of the inverter.

| Parameter | Value |
|---|---|
| output voltage Vc | 220 V |
| DC voltage E | 400 V |
| Filter inductance L | 2 mh |
| Resistance R | 20 Ω |
| Filter capacitor C | 20 uF |
| frequency F | 10 kHz |

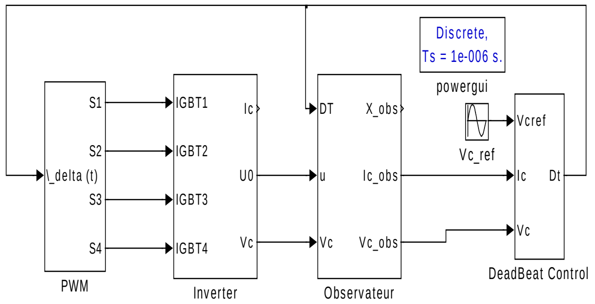



Fig.5. shows the simulation of a deadbeat control with observer by Matlab.

In this part, the system's simulation results are presented with the observer, in order to show the latter's role in replenishing the voltage $V_C$ and ensuring a good release of disturbance when connecting charges.

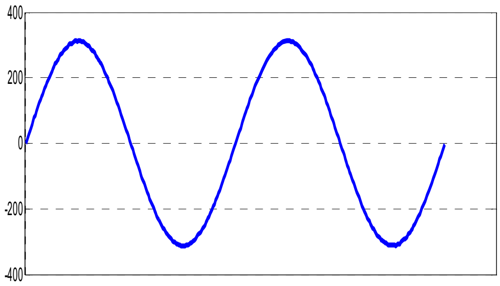



Fig.6. Simulation result of Voltage Vc observer.

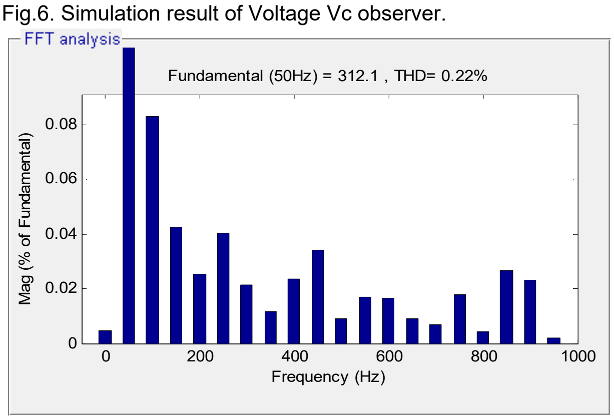



Fig.7 total harmonic of output inverter

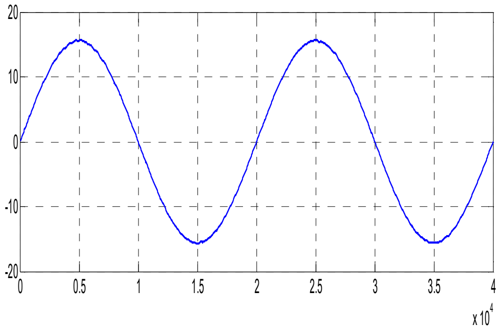



Fig.8. Current observer of Load.

## 6. P.I.L implementation

As seen in the image below, The DSP FA28253 is connected to the computer using a USB cable, which is the hardware configuration required for P.I.L simulation.

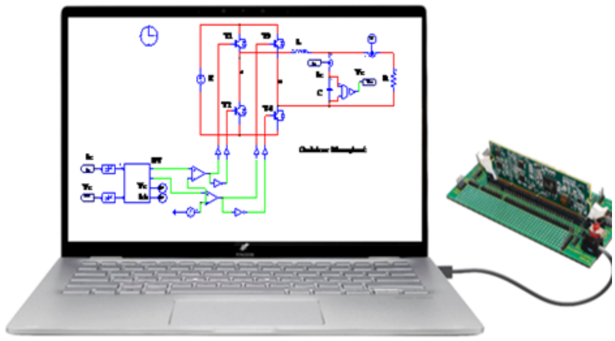


Fig.9. P.I.L of deadbeat control whit observer.

Figure 10 illustrates a simulated block diagram using the PSIM-developed P.I.L structure to enable quick and safe prototyping. The creator code CCS has been substituted for the control blocks (deadbeat) that were previously present.

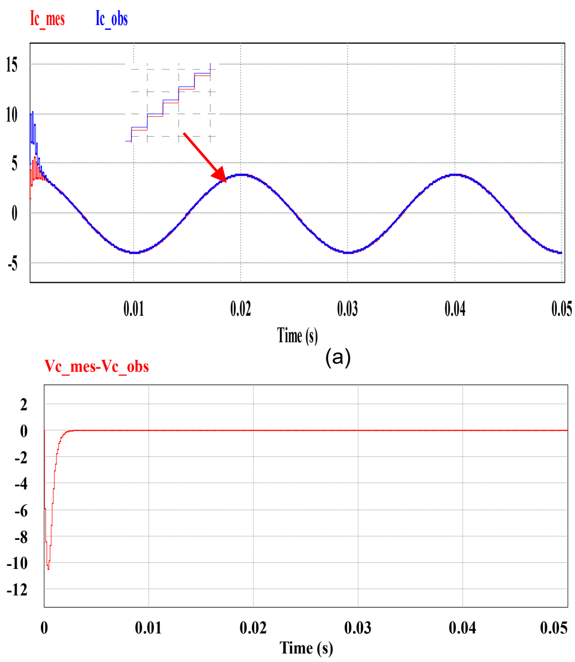
The PSIM software and the FA28253 are communicated with through this block using the UART communication protocol.

The inverter output voltage values, which are input from the contact block, are supplied to the microcontroller at each step of the PSIM.

The contact block's output, the inverter control's switching data (t1, t2, t3, and t4), is provided to the microcontroller. This structure is used to build the partnership between FA28253 and PSIM.

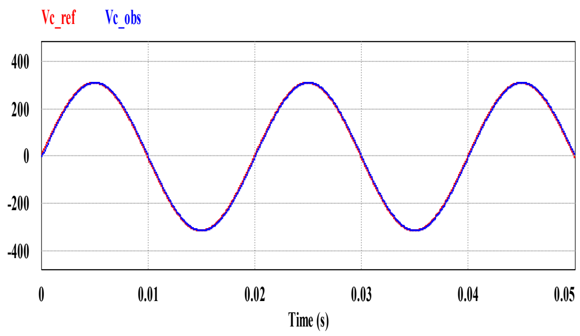
- **Test 01 Linear load with R=20Ω**

Figure 10 shows the result of observer deadbeat control of a single-phase inverter under a resistive load equal to 20Ω. The results of the simulation are presented below. Using a current sensor and the observer current. To show the effect of load variation, non-linear load and purely inductive load on the system.

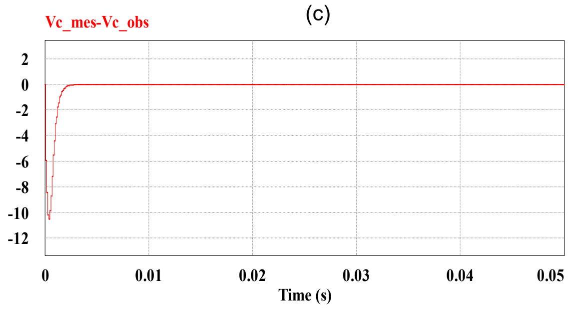



(a)

(b)



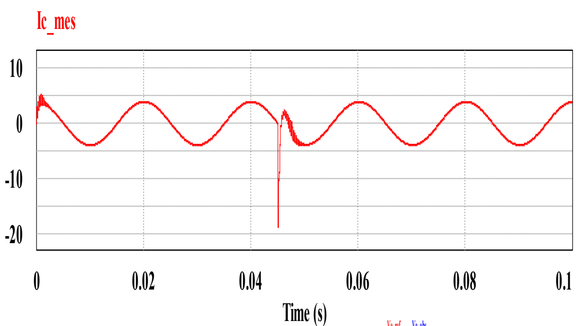

(c)



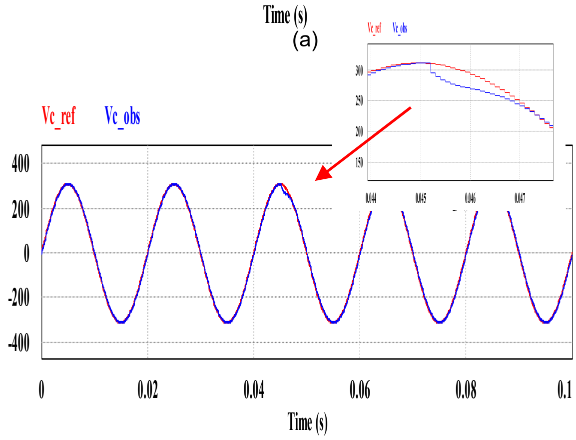

(d)

Fig. 10. P.I.L simulation of control inverter with observer, (a) current (Ic measured and observed), (b) error current (c) voltage ( Vc reference and observed) (d) error voltage.

To determine the reliability of the linear overload command, we first conduct preliminary testing. Car indicates the solely capacitive current, which is sinusoidal in nature and phase-shifted 90 degrees ahead of the voltage. The error of current and voltage between the measurement system and the estimated system is almost negligible, and the observer system controls and injects the measurement voltage feedback fault.




(a)




(b)

(b)

Figure.11 PIL simulation of a deadbeat control with the load increased to 100%, where R=40, (a) current (Ic measured and observed), and (b) voltage (Vc reference and observed).

- **Test 02 Linear load with R=20Ω at time 0.045 s on increasing the load up to 100% is equal R=40Ω.**

P.I.L simulation of deadbeat control with increasing the load up to 100% is presented in figure 11.

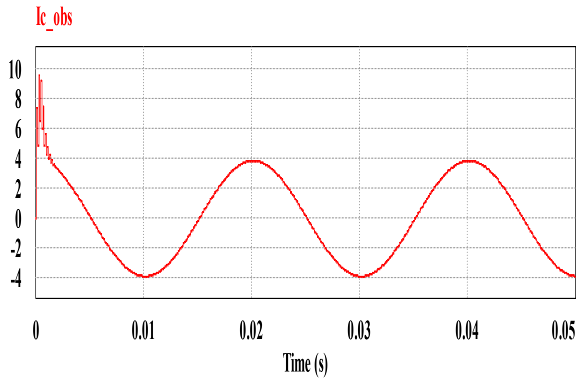
Figure.11 shows a PIL simulation of a deadbeat control with the load increased to 100%, where R=40, (a) current (Ic measured and observed), and (b) voltage (Vc reference and observed).

Figure 11 depicts the P.I.L results for output voltage and current under a resistive load at t = 0.045 s, When the load is increased to 100%, We observe a voltage loss when the load is increased to 100%, but the control soon makes up for it.

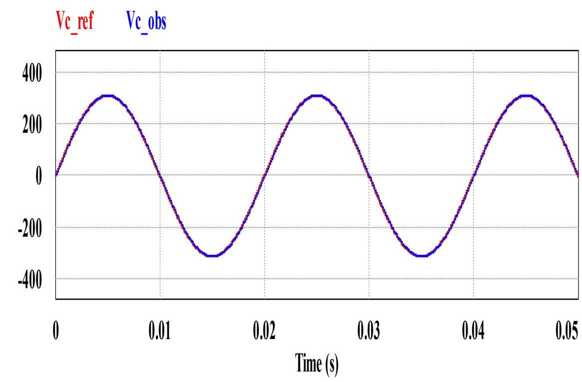
- **Test 05 Purely inductive load L= 0.10 H**

Figure 13 presented P.I.L simulation of deadbeat control with inductive load L=0.10 H.

The figure below shows P.I.L results for the output voltage and current for a purely inductive load.




(a)




(b)

Figure 12. P.I.L simulation of deadbeat control with purely inductive load L=0.10 H. (a) current (Ic observed), (b) voltage ( Vc reference and observed).

Although the control quickly recovers from the voltage drop that we see, the capacitor current waveform deviates from the ideal sinusoidal pattern. Results of P.I.L for output voltage and current with a purely l inductive load. Although the control quickly recovers from the voltage drop that we see, the capacitor current waveform deviates from the ideal sinusoidal pattern.

## 7. Conclusion

This paper describes a deadbeat control strategy for a single-phase inverter with an observer. Simulation and implementation in a processor-in-the-loop P.I.L have proven the viability of the suggested controller with observer. The findings demonstrated that the suggested strategy produces good voltage regulation with both linear and nonlinear loads.

The suggested controller requires a model of the system to calculate the controlled variables; it has no adjustable parameters. And this enables the voltage control to react dynamically quickly. It has been demonstrated that using an observer makes it possible to estimate the unknown capacitor current more accurately.

Considering the discrete nature of the converters and the microprocessors utilized for the control, deadbeat control offers a distinct method for controlling power converters. Additionally, the high computation power of the current DSPs makes this method for controlling power converters very alluring.

In conclusion, if the right tuning polynomial is applied, deadbeat current control is a promising control method. The route of future research may be to conduct experimental tests to confirm the dense simulations carried out here.

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