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# Comprehensive Design and Analysis of A Cascade Loop Resonant-Statefeedback Control Strategy for A Voltage Source Inverter

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**Abstract**

This paper presents a Resonant-State Feedback cascade control strategy for a voltage source inverter (VSI), aimed at achieving complete controllability of the system. Specifically, a pole placement technique-based state feedback is utilized in the current loop, which facilitates comprehensive control over both current and voltage states, enhances system dynamics, and effectively rejects disturbances. A classical resonant controller is employed in the outer voltage loop to minimize steady-state error and compensate for harmonic distortion induced by the load. The proposed digital control strategy accounts for computational delays inherent in digital systems by integrating a phase delay compensator within the voltage loop. Simulation studies conducted using MATLAB demonstrate that the control system can effectively regulate output voltage, achieving Total Harmonic Distortion (THD) levels of only 1.21% and 2.31%, respectively, even under nonlinear load conditions. These results underscore the effectiveness of the proposed control strategy.

**Keywords:** Voltage source inverter, Resonant Controller, Statefeedback Controller

## 1. Introduction

A Voltage Source Inverter (VSI) is a fundamental element in contemporary power electronics, responsible for converting direct current (DC) into alternating current (AC) while ensuring a stable output voltage. VSIs find extensive applications in various fields, including renewable energy systems, motor drives, and uninterruptible power supplies (UPS) [1]-[4].

Numerous studies have addressed the design of VSI output voltage with a Total Harmonic Distortion (THD) content of 2.5% across diverse load conditions. A dual-loop Proportional-Integral (PI) controller has been proposed for inverter control [5]; however, the phase delay in the output voltage due to the integral term remains unresolved. A control system for the VSI utilizing a Deadbeat controller, incorporating decoupling components, is presented in [6]. This approach includes a phase corrector scheme to mitigate time delays, although it struggles to maintain performance amid parameter variations. A repetitive control algorithm for VSIs based on Field Programmable Gate Array (FPGA) technology is discussed in [7], yet the complexity of the high-order digital controller limits its practical application.

State feedback control is widely utilized in power supply applications due to its design simplicity and effectiveness in disturbance rejection [8]. In this research, we design a state feedback controller for the current loop using the pole placement method, ensuring full controllability of system states under various operating conditions.

The resonant controller has gained popularity for its superior performance in eliminating steady-state errors [10-12] and effectively rejecting harmonic distortions introduced by loads. This paper proposes a classical resonant controller for the VSI, enhanced by a phase delay technique to improve control performance.

The paper organization is as follows: In section II, the VSI model are analyzed. Section III is the design methodology of statefeedback current and resonant voltage loop controller. In Section IV, simulation results are carefully evaluated to verify the efficiency of the proposed method. Conclusion and reference are presented at the end of the paper.

## 2. System Modeling

### 2.1. Continuous time state model

If consider load current $i_o(t)$ as a disturbance input to the system. The VSI state model can be derived [6]:

$$\begin{cases} \dot{x}(t) = Ax(t) + Bv_{inv}(t) + Ei_o(t) \\ y(t) = Cx(t) \end{cases} \quad (1)$$

Where, $x = [i_L \quad v_C]^T$, and the cofficient matrices are defined as:

$$A = \begin{bmatrix} 0 & -1/L_f \\ 1/C_f & 0 \end{bmatrix}, B = \begin{bmatrix} 1/L_f \\ 0 \end{bmatrix}, E = \begin{bmatrix} 0 \\ -1/C_f \end{bmatrix}, C = [1 \quad 0]$$

### 2.2. Discrete time state model

For digital implementation of the control system, the discrete model can be determined as:

$$\begin{cases} x_d[k+1] = F_d x_d[k] + G_d v_{inv}[k] + J_d i_g[k] \\ y_d[k] = H_d x_d[k] \end{cases} \quad (2)$$

In which:

$$F_d = \begin{bmatrix} cos(\omega_{res}T) & -\frac{sin(\omega_{res}T)}{L_f\omega_{res}} \\ \frac{sin(\omega_{res}T)}{C_f\omega_{res}} & cos(\omega_{res}T) \end{bmatrix}, G_d = \begin{bmatrix} \frac{sin(\omega_{res}T)}{L_f\omega_{res}} \\ 1 - cos(\omega_{res}T) \end{bmatrix}, J_d = \begin{bmatrix} 1 - cos(\omega_{res}T) \\ -\frac{sin(\omega_{res}T)}{C_f\omega_{res}} \end{bmatrix}$$

$\omega_{res} = \sqrt{1/L_f C_f}$ is the resonant frequency of the LC filter, and T is the sampling period.

## 3. A Case Study

The system parameters are expressed in Table 1:

***Table 1.*** *Ambient temperature changes by hour of day*

| Parameters | Value |
|---|---|
| Filter capacitance | 25 $\mu C$ |
| Filter inductance | 200$\mu H$ |
| Transformer ratio | 5/3 |
| Carrier frequency | 18kHz |
| Fundamental frequency | 400Hz |

## 3. Control System Design

### 3.1. The overall control system

The proposed cascade loop control diagram is expressed in Figure 1. In this diagram, $G_P(z)$ is the loop voltage proportional resonant controller function, $G_i(z)$ is the open loop function of the LC filter, and K is statefeedback gain matrix, $K = [K_1 \quad K_2]$.

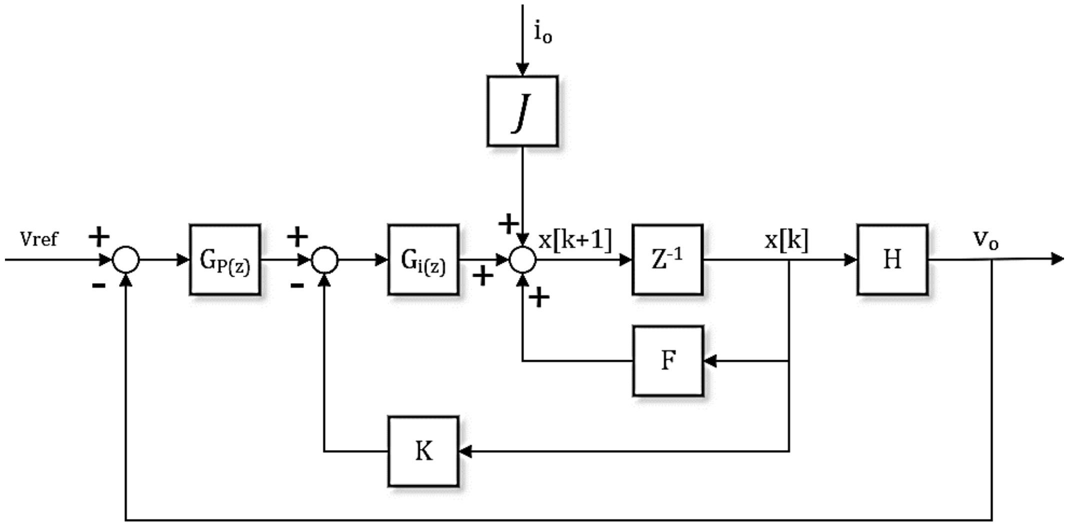



**Figure 1.** Overall control system.

The discrete time state space model hence can be rewritten as follow:

$$\begin{cases} x[k+1] = (F - GK)x[k] + Gu[k] + Ji_o[k] \\ y[k] = Hx[k] \end{cases} \quad (3)$$

### 3.2. Statefeedback control design

With the parameter on the Table 1, all the coefficient matrices can be calculated, as below:

$$A = \begin{bmatrix} -1000 & -5000 \\ 40000 & -3.67e4 \end{bmatrix}; \quad B = \begin{bmatrix} 1.2e6 \\ 0 \end{bmatrix}; \quad C = [0 \quad 1]; \quad D = 0 \quad (4)$$

And the statefeedback gain matrix can be determined based on pole placement method [1]:

$$K = [-0.0197 \;\; 0.01527] \quad (5)$$

### 3.3. Resonant controller design

To simplify the voltage loop control design, the inner current loop transfer function is considered unity, so the continuous time inverter model used to design the can be derived [8]:

$$G_{vol}(s) = \frac{1}{sC} \quad (6)$$

The resonant controller function can be written:

$$G_R(s) = K_r \frac{s\cos(\theta_n) - \omega_n \sin(\theta_n)}{s^2 - \omega_n^2} \quad (7)$$

with $\boldsymbol{K_r}$ is the resonant gain and $\boldsymbol{\omega_n}$ is the n$^{th}$ compensator resonance frequency.

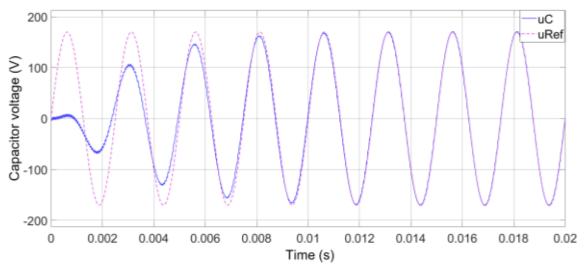
Through Zero Order Hold (ZOH) technique, discrete resonant controller function can be obtained:

$$G_R(z) = \frac{(z-1)\sin(\omega_n T_s)\cos(\theta_n) - (z+1)[1 - \cos(\omega_n T_s)]\sin(\theta_n)}{[z^2 - 2\cos(\omega_n T_s)z + 1]\omega_n} \quad (8)$$

## 4. Results And Discustion

### 4.1. Resistive load condition

The first Matlab simulation is performed for the case of linear load. It can be seen from Figure 2 that the output voltage is controlled just after 0.01s, and the voltage deviation is kept almost zero, and the THD content is just 1.1%. The inductor current waveform and its THD content are also depicted in Figure 3, in which, the current is controlled exactly in phase with the voltage, which demonstrate the efficient of the statefeedback current controller.



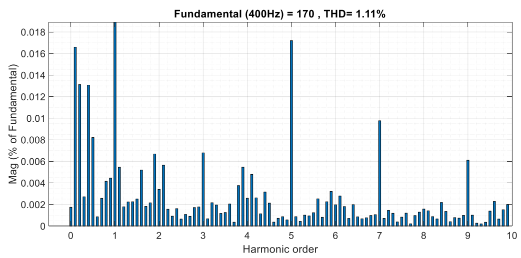



**Figure 2.** Output voltage under linear load condition.

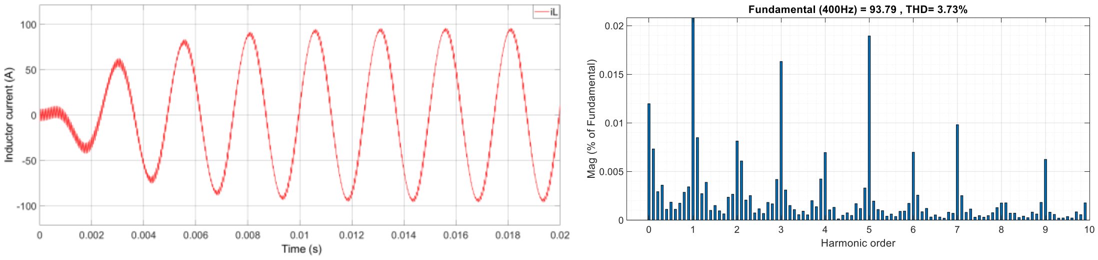



**Figure 3.** Inductor current under linear load condition.

## 4.2. Nonlinear load condition

To further investigate the effectiveness of the proposed control method, the control system is tested under nonlinear load condition, which is composed of a full wave diode rectifier, a filter capacitor, and a resistive load.

### 4.2.1. With only fundamental controller is used:

The control system is first verified with only fundamental controller is used for resonant voltage loop control. It can be seen from Figure 4 and 5 that the harmonic distortions in both the output voltage and inductor current waveform, the voltage THD is significantly increased to 2.51%, with the high percentage of the $3^{rd}$ harmonic component.

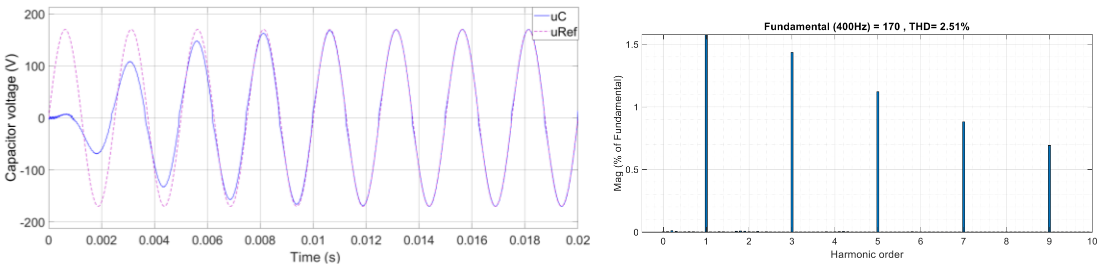



**Figure 4.** Output voltage under nonlinear load condition with only fundamental controller.

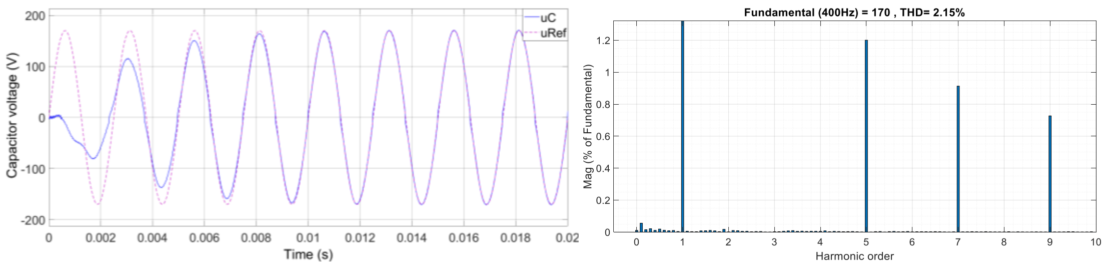



**Figure 5.** Inductor current under nonlinear load condition with only fundamental controller.

### 4.2.2. With $3^{rd}$ harmonic compensator is added

The control system is next validated with 3rd harmonic compensator is added in resonant voltage control scheme. Figure 6 and 7 depict the result of voltage, current waveforms and THD contents. Now the output voltage THD is dropped from 2.51% in previous case to just 2.15%, and the $3^{rd}$ harmonic component is greatly decreased to the value closed to zero, which prove the role of 3rd harmonic compensator in controlling the harmonics caused by nonlinear load.

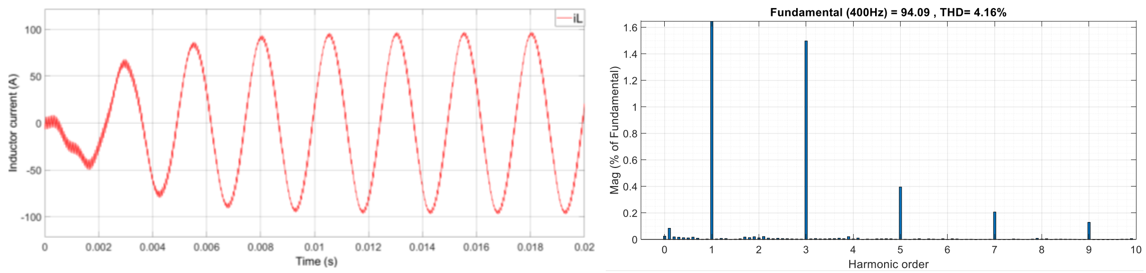



**Figure 6.** Output voltage under nonlinear load condition with 3rd compensator is in use.

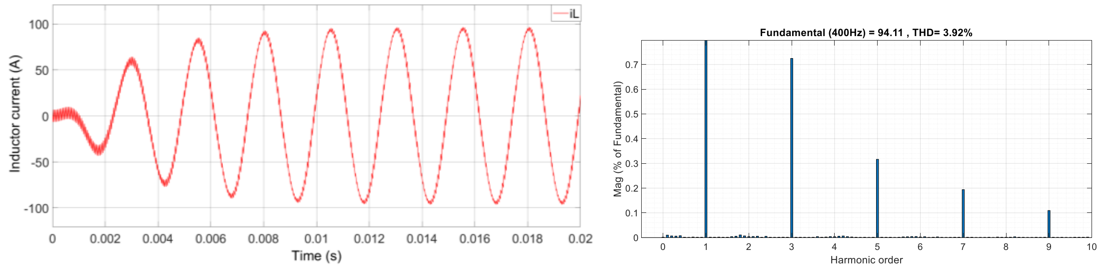



**Figure 7.** Inductor current under nonlinear load condition with 3rd compensator is in use.

## 4. Conclusion

In this paper, the state space equation of the 400Hz VSI is first modeled in both continuous time and discrete time domain. Then, a cascade loop control Resonant-Statefeedback is proposed to control the GPU system. In which, the statefeedback control scheme is performed for the inner current loop based on pole placement technique, to control the inductor current, improve system dynamic. In outer loop voltage, the classical resonant controller is offered to control the fundamental voltage, also compensate the harmonic distortion caused by the nonlinear load. The proposed control method is validated through Matlab simulations. The simulation results have demonstrated the validness of this control approaches, especially in the case of nonlinear load operation.

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## References

1. Z. Song, S. Krüner and C. M. Hackl, "Modeling and Proportional-Integral State Feedback Control of Fully Parallel Grid-Connected Inverters," in *IEEE Open Journal of the Industrial Electronics Society*, vol. 6, pp. 618-636, 2025, doi: 10.1109/OJIES.2025.3557702.
2. N. Diao, X. Zhang, R. Zhang, Y. Zhang, X. Guo and Y. Wei, "A Hybrid-Model-Flux-Observer-Based Horizon-Adaptive Sliding Integration Fault Diagnosis Method for Sensorless Vector Controlled Voltage Source Inverter," in *IEEE Transactions on Instrumentation and Measurement*, vol. 74, pp. 1-11, 2025, Art no. 3529311, doi: 10.1109/TIM.2025.3557119.
3. H. Ren, C. Gan, K. Ni, H. Shi, C. Zhang and R. Qu, "Flexible Active Vector Distribution Strategy for Current Ripple and Switching Loss Reduction in Three-Phase Voltage Source Inverter," in *IEEE Transactions on Industry Applications*, vol. 61, no. 2, pp. 3234-3245, March-April 2025, doi: 10.1109/TIA.2024.3523462.
4. H. Tian, W. Han, M. Chen, G. Liang and Z. Tang, "Common-Ground Type Switching Step-Up/Step-Down VSI for Grid-Connected PV System," in *IEEE Transactions on Power Electronics*, vol. 39, no. 8, pp. 10390-10398, Aug. 2024, doi: 10.1109/TPEL.2024.3393624.
5. Ma, Xuejun & Wu, Hongxia & Sun, Song & Huang, Congsheng. (2007). Control method with digital PI dual close-loop for inverter.
6. Devika Manohar, SeemaP.N: Deadbeat Controller with Phase Corrector for 400-Hz Inverter used in Ground Power Units of Aircrafts. IEEE International Conference on Technological Advancements in Power & Energy, 978-1-4799-8280-6/15 (2015).

7. DA. Lidozzi, L. Solero, F. Crescimbini, C. Ji, S. Bifaretti and P. Zanchetta: FPGA-based direct repetitive control for high performance ground power units. IEEE Energy Conversion Congress and Exposition (ECCE), pp. 3063-3068 (2017).
8. J. Kukkola, M. Hinkkanen and K. Zenger, "Observer-Based State-Space Current Controller for a Grid Converter Equipped With an LCL Filter: Analytical Method for Direct Discrete-Time Design," in IEEE Transactions on Industry Applications, vol. 51, no. 5, pp. 4079-4090, Sept.-Oct. 2015.
9. B. Li, M. Zhang, L. Huang, L. Hang and L. M. Tolbert, "A new optimized pole placement strategy of grid-connected inverter with LCL-filter based on state variable feedback and state observer," 2013 Twenty-Eighth Annual IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 2013, pp. 2900-2906.
10. Z. Li, Y. Li, P. Wang, H. Zhu, C. Liu and F. Gao, "Single-Loop Digital Control of High-Power 400-Hz Ground Power Unit for Airplanes," in IEEE Transactions on Industrial Electronics, vol. 57, no. 2, pp. 532-543, Feb. 2010, doi: 10.1109/TIE.2009.2033490.
11. J. Tian, J. Petzoldt, T. Reimann, M. Scherf and G. Berger, "Control system analysis and design of a resonant inverter with the variable frequency variable duty cycle scheme," 2006 37th IEEE Power Electronics Specialists Conference, Jeju, Korea (South), 2006, pp. 1-5, doi: 10.1109/pesc.2006.1711829.
12. Son, T.Q., Trung, N.K., Quang, D.N., Quy, D.N., Phu, D.B. (2023). Control Design for 400 Hz Ground Power Unit. In: Nguyen, T.D.L., Lu, J. (eds) Machine Learning and Mechanics Based Soft Computing Applications. Studies in Computational Intelligence, vol 1068. Springer, Singapore. https://doi.org/10.1007/978-981-19-6450-3_11.
13. J. Jiao, J. Y. Hung and R. M. Nelms, "State feedback control for single-phase grid-connected inverter under weak grid," *2017 IEEE 26th International Symposium on Industrial Electronics (ISIE)*, Edinburgh, UK, 2017, pp. 879-885, doi: 10.1109/ISIE.2017.8001362.