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An Observer-Based Optimal Voltage Control Scheme for Three-Phase UPS Systems


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ABSTRACT

This paper proposes a simple optimal voltage control method for three-phase uninterruptible-power-supply systems. The proposed voltage controller is composed of a feedback control term and a compensating control term. The former term is designed to make the system errors converge to zero, whereas the latter term is applied to compensate for the system uncertainties. Moreover, the optimal load current observer is used to optimize system cost and reliability. Particularly, the closed-loop stability of an observer-based optimal voltage control law is mathematically proven by showing that the whole states of the augmented observer-based control system errors exponentially converge to zero. Unlike previous algorithms, the proposed method can make a tradeoff between control input magnitude and tracking error by simply choosing proper performance indexes. The effectiveness of the proposed controller is validated through simulations on MATLAB/Simulink and experiments on a prototype 600-VA testbed with a TMS320LF28335 DSP. Finally, the comparative results for the proposed scheme and the conventional feedback linearization control scheme are presented to demonstrate that the proposed algorithm achieves an excellent performance such as fast transient response, small steady-state error, and low total harmonic distortion under load step change, unbalanced load, and nonlinear load with the parameter variations.

INTRODUCTION

Uninterruptible power supply (UPS) systems supply emergency power in case of utility power failures. Recently, the importance of the UPS systems has been intensified more and more due to the increase of sensitive and critical applications such as communication systems, medical equipment, semiconductor manufacturing systems, and data processing systems. These applications require clean power and high reliability regardless of the electric power failures and distorted utility supply voltage. Thus, the performance of the UPS systems is usually evaluated in terms of the total harmonic distortion (THD) of the output voltage and the transient/steady state responses regardless of the load conditions: load step change, linear load, and nonlinear load. To improve the aforementioned performance indexes, a number of control algorithms have been proposed such as proportional–integral (PI) control, Hloop-shaping control, model predictive control, deadbeat control, sliding-mode control, repetitive control, adaptive control, and feedback linearization control (FLC).

The conventional PI control suggested in and is easy to implement; however, the THD value of the output voltage is not low under a nonlinear-load condition. In, the Hloop-shaping control scheme is described and implemented on a single-phase inverter, which has a simple structure and is robust against model uncertainties. A model predictive control method for UPS applications is described in. By using a load

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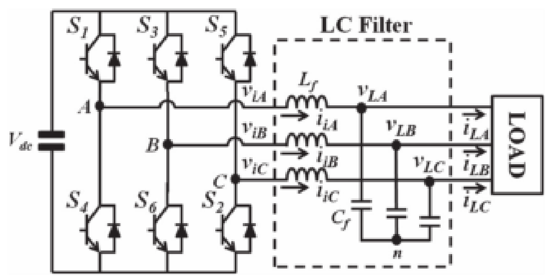
current observer in place of current sensors, the authors claimed a reduced system cost. However, the simulation and experimental results do not reveal an exceptional performance in terms of THD and steady-state error. In, the deadbeat control method uses the state feedback information to compensate for the voltage drop across the inductor. However, this method exhibits sensitivity to parameter mismatches, and the harmonics of the inverter output voltage are not very well compensated.Inand , the sliding-mode control technique reflectsrobustness to the system noise, and still, the control system has a well-known chattering problem. In, repetitive control is applied to achieve a high-quality sinusoidal output voltage of a three-phase UPS system. Generally, this control techniquehasa slow response time. In, the adaptive control method with low THD is proposed; nevertheless, there is still a risk of divergence if the controller gains are not properly selected. Multivariable FLC is presented in. In this control technique, the nonlinearity of the system is considered to achieve low THD under nonlinear load. However, it is not easy to carryout due to the computation complexities. As a result, the aforementioned linear controllers are simple, but the performance is not satisfactory under nonlinear load. In contrast, the nonlinear controllers have an outstanding performance, but the implementations not easy due to the relatively complicated controllers.

So far, the optimal control theory has been researched in various gelds such as aerospace, economics, physics, and so on, since it has a computable solution called a performance index that can quantitatively evaluate the system performance by contrast with other control theories. In addition, the optimal control design gives the optimality of the controller according to a quadratic performance criterion and enables the control system to have good properties such as enough gain and phase margin, robustness to uncertainties, good tolerance of nonlinearities, etc. Hence, a linear optimal controller has not only a simple structure in comparison with other controllers but also a remarkable control performance similar to other nonlinear controllers.

Therefore, this paper proposes an observer-based optimal voltage control scheme for three-phase UPS systems. This proposed voltage controller encapsulates two main parts: feedback control term and a compensating control term. The former term is designed to make the system errors converge to zero, and the latter term is applied to estimate the system uncertainties. The Lyapunov theorem is used to analyze testability of the system. Specially, this paper proves the closedloopstability of an observer-based optimal voltage control law by showing that the system errors exponentially convergetozero. Moreover, the proposed control law can be systematically designed taking into consideration a tradeoff between controlinputmagnitude and tracking error unlike previous algorithms. The efficacy of the proposed control method is varied via simulations on MATLAB/Semolina and experiments on a prototype600-VA UPS inverter tested with a TMS320LF28335DSP. In this paper, a conventional FLC method unselected to demonstrate the comparative results because it has a good performance under a nonlinear-load condition, and its circuit model of a three-phase inverter in is similar tour system model. Finally, the results clearly show that the proposed scheme has a good voltage regulation capability such as fast transient behavior, small steady-state error, and loathed under various load conditions such as load step change, unbalanced load, and nonlinear load in the existence of the parameter variations.



Three-phase inverter with an LC alters for a UPS system.

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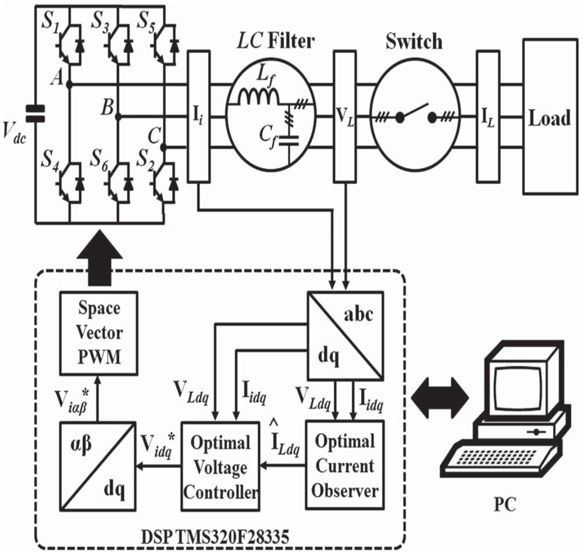
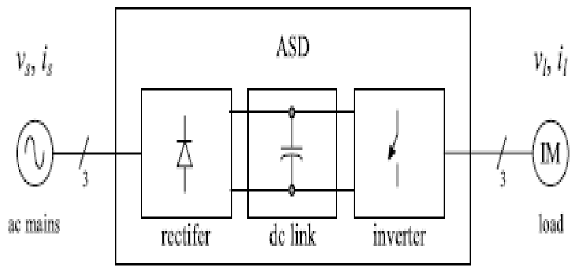
BLOCK DIAGRAM:



The main objective of static power converters is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs); uninterruptible power supplies (UPS), static vary compensators, active filters, flexible ac transmission systems (FACTS), and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency, and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverters (VSIs), where the independently controlled ac output is a voltage waveform.

These structures are the most widely used because they naturally behave as voltage sources as required by many industrial applications, such as adjustable speed drives(ASDs), which are the most popular application of inverters; Similarly, these topologies can be found as current source inverters (CSIs), where the independently controlled ac output is a current waveform. These structures are still widely used in medium-voltage industrial applications, where high-quality voltage waveforms are required.

Static power converters, specifically inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature fast transitions rather than smooth ones. For instance, the ac output voltage produced by the VSI of a standard ASD is a three-level



Basic designs:

In one simple inverter circuit, DC power is connected to a transformer through the centre tap of the primary winding. A switch is rapidly switched back and forth to allow current to flow back to the DC source following two alternate paths through one end of the primary winding and then the other. The alternation of the direction of current in the primary winding of the transformer produces alternating current (AC) in the secondary circuit.

The electromechanical version of the switching device includes two stationary contacts and a spring supported moving contact. The spring holds the movable contact against one of the stationary contacts and an electromagnet pulls the movable contact to the opposite stationary contact. The current in the electromagnet is interrupted by the action of the switch so that the switch continually switches rapidly back and forth. This type of electromechanical inverter switch, called a vibrator or buzzer, was once used in vacuum tube automobile radios. A similar mechanism has been used in door bells, buzzers and tattoo. As they became available with adequate power ratings, transistors and various other types of semiconductor switches have been incorporated into inverter circuit designs.

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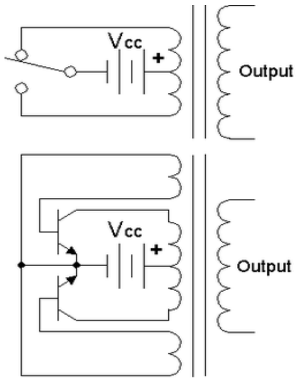
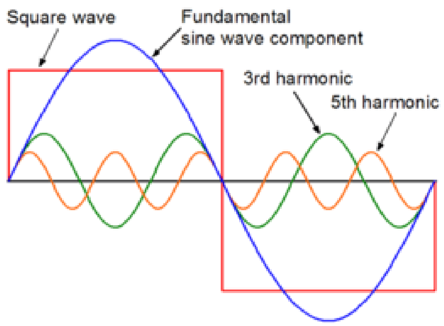


Output waveforms:

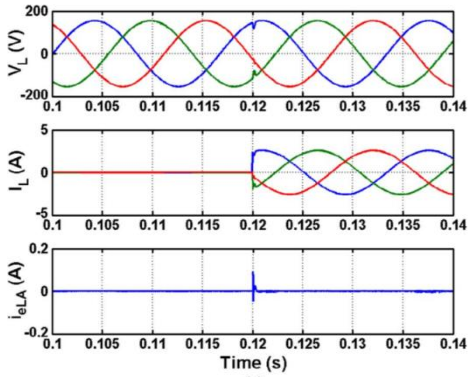
The switch in the simple inverter described above, when not coupled to an output transformer, produces a square voltage waveform due to its simple off and on nature as opposed to the sinusoidal waveform that is the usual waveform of an AC power supply. Using Fourier analysis, periodic waveforms are represented as the sum of an infinite series of sine waves. The sine wave that has the same frequency as the original waveform is called the fundamental component. The other sine waves, called harmonics that are included in the series have frequencies that are integral multiples of the fundamental frequency.

The quality of the inverter output waveform can be expressed by using the Fourier analysis data to calculate the total harmonic distortion (THD). The total harmonic distortion is the square root of the sum of the squares of the harmonic voltages divided by the fundamental voltage:

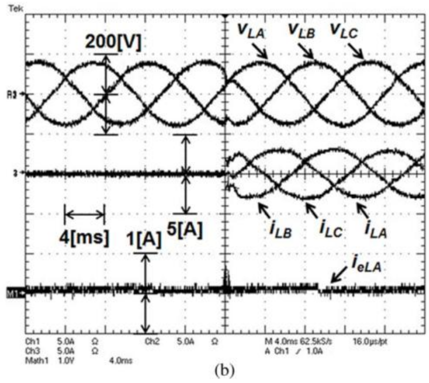
$$\mathrm{THD} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2}}{V_1}$$



SIMULATION RESULTS



(a)



(b)

CONCLUSION

This paper has proposed a simple observer-based optimal voltage control method of the three-phase UPS systems The proposed controller is composed of a feedback control term to stabilize the error dynamics of the system and a compensating control term to estimate the system uncertainties. Moreover, the optimal load current observer was used to optimize system cost and reliability. This paper proved the closed-loop stability of an observer-based optimal voltage controller by using theLyapunov theory. Furthermore, the proposed voltage control law can be methodically designed taking into account a tradeoff between control input magnitudes and tracking error unlike previous algorithms. The superior performance of the proposed control system was demonstrated through simulations and experiments. Under three load conditions (load step change, unbalanced load, and nonlinear load), the proposed control scheme revealed a better voltage tracking performance such as lower THD, smaller steady-state error, and faster transient response than the conventional FLC scheme even if there exist parameter variations.

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