Fuzzy-Tuning PID Control of an Inverter with Rectifier-Type Nonlinear Loads

Li Jian, Kang Yong, and Chen Jian, *Senior Member, IEEE*
Department of Electrical Engineering, Huazhong University of Science and Technology, Wuhan, 430074, P. R. China
Phone: 86-27-87543071 Fax: 86-27-87540937
E-mail: *lijian_no1@371.net*

Abstract - *The fuzzy-tuning proportional-integral-derivative (PID) control of an inverter with rectifier-type nonlinear loads is described in this paper. The inverter system employs closed-loop instantaneous voltage feedback PID control with a sinusoidal reference implemented using a TI TMS320F240 digital signal processor (DSP). The output voltage error and its derivative are used as input variables of the fuzzy logic controller (FLC) to adjust the feedback gain of the system. Simulation and experiment results prove that the proposed converter is able to produce a low total harmonic distortion (THD) in the inverter output and fast dynamic response for rectifier-type nonlinear loads.*

Key words: fuzzy control; digital PID; inverter; rectifier-type nonlinear loads; DSP

1. Introduction

Recently closed-loop regulated pulse-width-modulated (PWM) inverters have been widely used in many types of ac power conditioning systems. With the availability of high-frequency switching devices, the instantaneous feedback control (IFC) is proposed. Analog IFC of an inverter is employed to achieve excellent dynamic response and low total harmonic distortion (THD). However in the analog control, harmonic frequencies are spread over a wide range around the average switching frequency and the sub-cycle disturbance cannot be compensated completely.

Digital control has such advantages as simplification of control hardware and a corresponding reduction of cost in comparison with analog control. Deadbeat-controlled PWM inverter has very fast response for load disturbances and nonlinear loads [1-2]. But in the deadbeat control approach, the control signal depends on a precise PWM inverter load model and the performance of the system is sensitive to parameter and load variations. Repetitive-controlled is applied to generate high-quality sinusoidal output voltage in the inverter with rectifier-type nonlinear loads whereas its dynamic response is very slow[3].

The paper proposed a fuzzy-tuning proportional-integral-derivative (PID) control of an inverter with rectifier-type nonlinear loads. The inverter system employs closed-loop instantaneous voltage feedback PID control with a sinusoidal reference implemented using a TI TMS320F240 digital signal processor (DSP). The output voltage error and its derivative are used as input variables of the fuzzy logic controller (FLC) to adjust the feedback gain of the system. The FLC can handle nonlinearity and does not need accurate mathematical model. FLC is represented by if-then rules and thus can provide an understandable knowledge representation.

The digital PID control algorithm for the system is derived in Section 2.1 of this paper. Section 2.2 presents the FLC of the system feedback gain. Section 3 gives the experimental and simulation results that prove the proposed converter is able to produce a low THD in the inverter output and fast response for rectifier-type nonlinear loads. Section 4 concludes the paper.

2. Control Scheme

2.1 Digital PID Control

The circuit diagram of a single-phase half-bridge voltage-source inverter is shown in Fig. 1. It consists of a LC-filter and a rectifier-type nonlinear load. Fig. 2 shows the block diagram of the instantaneous voltage feedback digital PID controller of a PWM inverter. For the controller, it is desired to track a given reference voltage command with minimum tracking error in transient response and minimum THD in stead-state response.

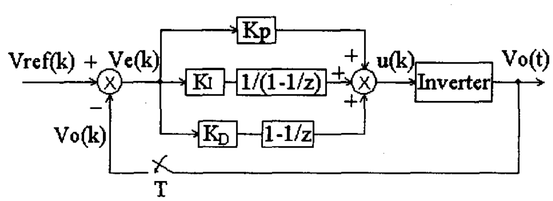

Fig. 1. Circuit diagram of an inverter with a LC-filter and a rectifier-type nonlinear load

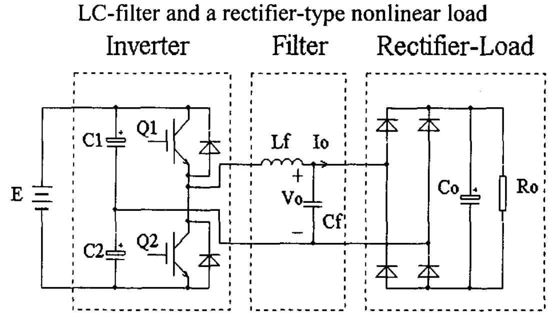

Fig.2.Block diagram of the digital PID controller of a PWM inverter

The purpose of the digital PID controller is that the voltage error ve(k) can be kept to a minimum value. The voltage error ve(k) is defined as

$$ve(k) = vref(k) - vo(k)$$

Where vref (k) is the specified sinusoidal voltage command and vo (k) is the measured output voltage. A digital PID controller is used to generate the required control voltage u (k) according to ve (k). It has the form

$$u(z) = K_P Ve(z) + \frac{K_I}{1-z^{-1}} Ve(z) + K_D(1-z^{-1})Ve(z)$$

And the incremental form of the algorithm can be derived as

$$u(k) = u(k-1) + \Delta u(k)$$

$$\Delta u(k) = K_P * [ve(k) - ve(k-1)] + K_I * ve(k) + K_D * [ve(k) - 2ve(k-1) + ve(k-2)]$$

PID controllers have been in use for the last few decades. They perform satisfactorily during transient under limited operating range. Implementation in analog or digital is cheap and straightforward. Since PID controller is based on linear model, response for large signal disturbance is poor. Hence the paper proposed fuzzy-tuning PID control scheme for rectifier-type nonlinear loads.

2.2 Fuzzy-Tuning Digital PID Control

Fig. 3 shows the block diagram of the proposed fuzzy-tuning PID controller of an inverter [4].

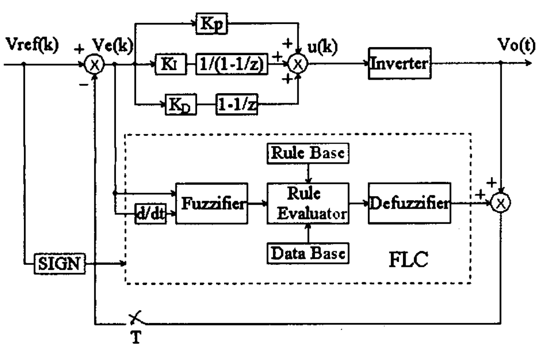

Fig. 3. Block diagram of the fuzzy-tuning PID controller of an inverter.

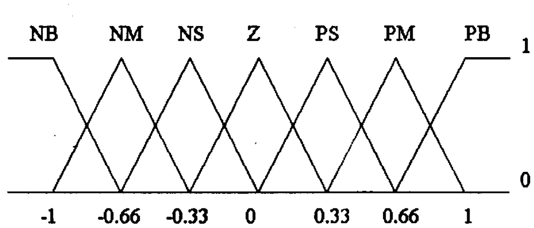

Fig. 4 Membership function of fuzzy variable

2.2.1 Fuzzy-State Variable

The most significant feature of fuzzy logic control (FLC) is that it provides a systematic approach to convert linguistic control strategy based on expert experience and knowledge to an automatic control strategy [5].

In the proposed control scheme, the feedback gain can be adjusted by FLC. The input variables to the FLC are the voltage error ve(k) and its derivation ve'(k).

$$ve'(k) = [ve(k) - ve(k-1)]/T$$

where T is the sample time. The output variable from the FLC is the feedback gain.

2.2.2 Fuzzification

Fuzzification converts crisp data into fuzzy sets, making it comfortable with the fuzzy set representation of the state variable in the rule. In the fuzzification process, normalization by reforming a scale transformation is needed at first, which maps the physical values of the state variable into a normalized universe of discourse.

In the paper, each universe of discourse of two input and an output is divided into seven fuzzy subsets: positive big (PB), positive medium (PM), positive small (PS), zero (ZE), negative small (NS), negative medium (NM) and negative big (NB)[6]. The partition of fuzzy subsets and the shapes of the membership function are shown in Fig. 4.

2.2.3 Inference Method

The control rules for the feedback gain kf are shown in Fig. 5 according to the polarity of vref. The inference method employs MAX-MIN method, which is shown in Fig.6. The output membership function of each rule is given by minimum operator, whereas the combined fuzzy output is given by maximum operator.

When ve(k)=x0, ve'(k)=y0,

C1: $\omega 1 = \mu A1(x0) \wedge \mu B1(y0)$

C2: $\omega 2 = \mu A1(x0) \wedge \mu B2(y0)$

C3: $\omega 3 = \mu A2(x0) \wedge \mu B1(y0)$

C4: $\omega 4 = \mu A2(x0) \wedge \mu B2(y0)$

change of voltage error (Ve') \ voltage error (Ve)	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PB	PM	PS	Z
NM	PB	PB	PB	PM	PS	Z	NS
NS	PB	PB	PM	PS	Z	NS	NM
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NB	NB	NB
PB	Z	NS	NM	NB	NB	NB	NB

(a).Vref $\geqslant$ 0

change of voltage error (Ve') \ voltage error (Ve)	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

(b).Vref < 0

Fig. 5 Control rules for the feedback gain of FLC

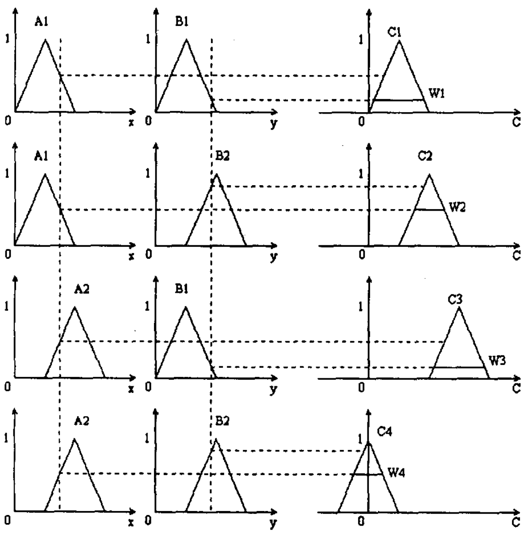

Fig.6. MAX-MIN Method

2.2.4 Defuzzification

The imprecise fuzzy control action generated from the inference must be transformed to a precise control action in real application. The height method is used to defuzzify the fuzzy variables.

$$Z^* = \sum_{j=1}^{n} \omega_i C_i \Big/ \sum_{j=1}^{n} \omega_i$$

Output denormalization maps the normalized value of the control output variable into physical domain.

2.3 Repetitive Compensation

Applying fuzzy-tuning PID controller of an inverter improves the system's transient responses and its robustness to load variations. When the inverter is connected with a rectifier-type nonlinear load, this kind of load results in periodic distortions of the output voltage waveform. Presently repetitive compensation will be applied to minimize the periodic distortions of the inverter. Fig. 7 shows the block diagram of the repetitive compensation fuzzy-tuning PID controller of an inverter.

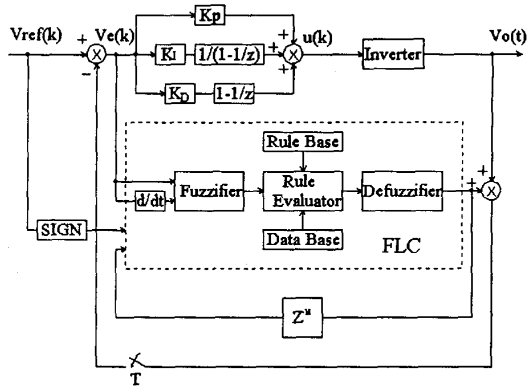

Fig. 7. Block diagram of the controller of an inverter.

3. Results

For the circuit of Fig. 1, the simulation of the proposed inverter is achieved by the software package MATLAB. Fig. 8(a) shows the simulation results of the output voltage and the current waveforms of the proposed converter. Fig. 8(b) illustrates the harmonics spectrum of the output voltage.

A single-chip DSP TMS320F240 provided by Texas Instruments is used to implement the proposed fuzzy-tuning PID control scheme of an inverter. The TMS320F240 has many good features, which includes a 50-ns instruction cycle, a 32-b arithmetic logic unit, a 32-b accumulator, a 16-b×16-b parallel multiplier, 544 words Dual-Access RAM, 16k words flash EEPROM and 224k words of addressable memory space. It also comprises some on-chip peripherals necessary for power converter, which includes an Event-Manager with 12-channel PWM outputs, dual 10-b A/D converter and a watchdog timer.

The software approach is adopted to realize fuzzy-tuning PID control algorithm. At first the fuzzy decision table was computed off-line using MATLAB. And then it was stored in the flash EEPROM of DSP. The fuzzy-tuning process is performed on a lookup table. So it can be executed very quickly.

To verify the effectiveness of the proposed controller, a low-power prototype is constructed and the proposed algorithm is tested. The following power circuit parameters are used:

DC bus voltage: E = 380V
Switching frequency: fs = 20kHz
Filter inductor: Lf = 1mH
Filter capacitor: Cf = 30uF
Reference sine wave: Vref = 150V peak at 50Hz
Rated load current: Io = 3A rms.
Electrolytic capacitor: Co = 2200uF

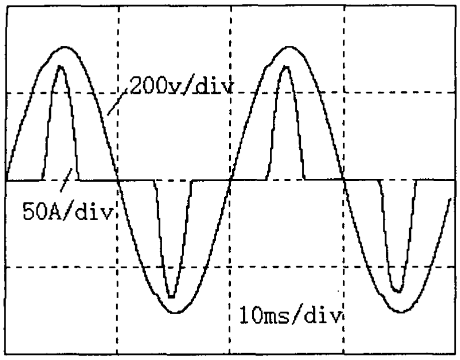

Fig. 8(a) Simulation results of the output voltage and the current waveforms

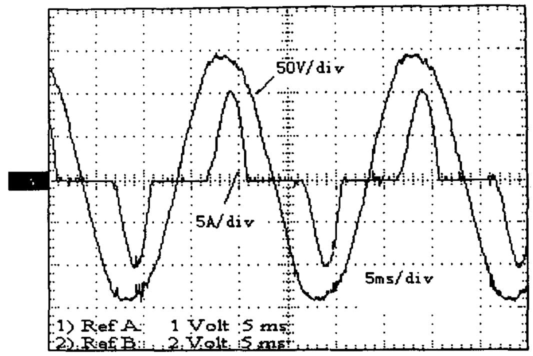

Fig. 9(a) Experimental results of the output voltage and the current waveforms

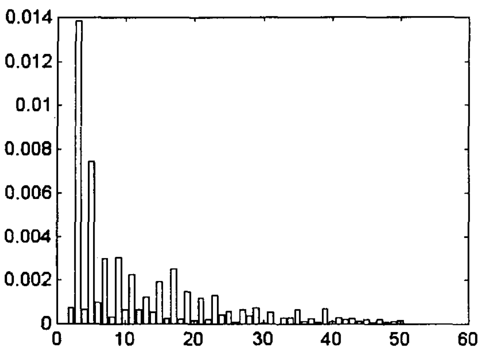

Fig. 8(b) Harmonics spectrum of the simulation output voltage. (THD=1.71%)

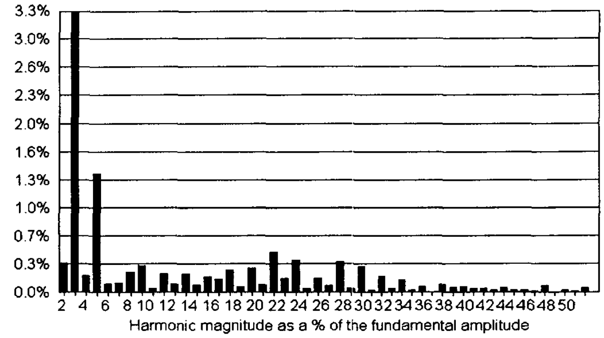

Fig. 9(b) Harmonics spectrum of the experimental output voltage. (THD=3.71%)

Fig. 9(a) shows the experimental results of the output voltage and the current waveforms of the proposed converter with rectifier-type nonlinear load. Fig.9 (b) illustrates the harmonics spectrum of the output voltage.

4. Conclusions

In this paper, fuzzy-tuning PID control of an inverter with rectifier-type nonlinear loads is presented. The inverter system employs closed-loop instantaneous voltage feedback PID control with a sinusoidal reference implemented using a TI TMS320F240 digital signal processor. The output voltage error and its derivative are used as input variables of the fuzzy logic controller to adjust the feedback gain of the system. The FLC can handle nonlinearity and does not need accurate mathematical model.

Experimental and simulation results proved that the THD of output voltage could be decreased significantly. In the future repetitive compensation will be applied to minimize the periodic distortions of the inverter.

References

[1] KALYAN P. GOKHALE, ATSUO KAWAMURA, and RICHARD G.HOFT, "Dead Beat Microprocessor Control of PWM Inverter for Sinusoidal Output Waveform Synthesis," IEEE Trans. Ind. Appl., vol. IA-23, NO. 5, pp. 901-910, 1987.

[2] Chihchiang Hua, "Two-Level Switching Pattern Deadbeat DSP Controlled PWM Inverter," IEEE Trans. Power. Electron., vol. 10, NO. 3, pp. 310-317, 1995.

[3] Ying-Yu Tzhou, Rong-shyang Ou, Shih-Liang Jung, and Meng-Yueh Chang, "High-Performance Programmable AC Power Source with Low Harmonic Distortion Using DSP-Based Repetitive Control Technique," IEEE Trans. Power. Electron., vol. 12, NO. 4, pp. 715-725, 1997 .

[4] Paolo Mattavelli, Leopoldo Rossetto, Giorgio Spiazzi, and Paolo Tenti, "General-Purpose Fuzzy Controller for DC-DC Converters," IEEE Trans. Power. Electron., vol. 12, NO. 1, pp. 79-86, 1997 .

[5] V.S.C. Raviraj, and P. C. Sen, "Comparative Study of Proportional-Integral, Sliding Mode, and Fuzzy Logic Controllers for Power Converters," IEEE Trans. Ind. Appl., vol.33, NO. 2, pp. 518-524, 1997.

[6] Wing-Chi So, Chi K. Tse, and Yim-Shu Lee, "Development of a Fuzzy Logic Controller for DC/DC Converters: Design, Computer Simulation, and Experimental Evaluation," IEEE Trans. Power. Electron., vol. 11, NO. 1, pp. 24-32, 1996 .