High-Performance DC-AC Power Converter Using Adaptive Control Technique for Advanced Material Machining

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***Abstract*—A high-performance DC-AC power converter using adaptive control technique for advanced material machining (AMM) is developed in this paper. The presented technique combines the merits of hyperbolic tangential sliding surface (HTSS) and adaptive neuro-fuzzy inference system (ANFIS). The HTSS not only has the robustness of classic SMC but increases the system trajectory convergence speed. However, once a highly nonlinear load occurs, the chattering still exists. The chattering causes high total harmonic distortion (THD) in DC-AC power converter output voltage, thus yielding the instability and unreliability of advanced material machining. The ANFIS is thus employed to eliminate the chattering and simultaneously the HTSS provides finite system-state convergence time. By combining HTSS with ANFIS, the DC-AC power converter of AMM will achieve robust performance. Experimental results are given to conform that the proposed technique can obtain low total harmonic distortion (THD) and fast transience even under phase-controlled loads. Owing to the notable superiorities, e.g. computational quickness, practical simplicity, and programmable easiness in the proposed technique, this paper will be a helpful reference to researchers of related advanced material machining.**

***Index Terms*—DC-AC power converter, advanced material machining (AMM), hyperbolic tangential sliding surface (HTSS), adaptive neuro-fuzzy inference system (ANFIS)**

I. Introduction

The DC-AC power converters are popularly used in advanced material machining (AMM), such as nickel-based super alloys, nuclear materials, and titanium alloys [1-4]. The requirements of a high-performance DC-AC power converter include output voltage with low THD even under nonlinear loads, fast transient under phase-controlled load and steady-state errors as small as possible. To obtain these requirements, proportional-integral (PI) controller is one of the useful ways to achieve suitable characteristics. But, PI is difficult for converter control to gain good steady-state and dynamic response under nonlinear loads [5-8]. Many control techniques are also used in literature, such as mu-synthesis, H-infinity control, wavelet control, and so on [9-14]. However, these techniques are complex, and difficult to realize. Proposed in 1950s, sliding mode control (SMC) provides insensitivity to parameter variations and removal of disturbances [15], [16]; SMC of DC-AC power converter systems are also developed. However, these SMC systems use linear sliding surface, and such surface has infinite system-state convergence time [17-20]. Thus to increase the convergence speed, a hyperbolic tangential sliding surface (HTSS) can be used. Compared with linear sliding-surface-based, the HTSS can enforce system tracking error to converge to zero in finite time [21-24]. However, when a severe nonlinear load is applied, the HTSS system still exists in chattering problem. The chattering will cause high THD in DC-AC power converter output and the stability and reliability of the AMM are thus deteriorated. Adaptive neuro-fuzzy inference system (ANFIS) associating the training ability of neural network with approximate human reasoning of fuzzy logic is well-known artificial intelligence approach. By such a hybrid learning approach, the error between desired and actual output can be minimized [25-28]. Therefore, the ANFIS is used to eliminate the chattering while the HTSS is utilized to achieve finite system-state convergence time. When this proposed technique is applied to the control of a DC-AC power converter of AMM, the system will show the effectiveness of low output voltage distortion, fast transient and insensitivity to load disturbances. Experimental results demonstrate

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the feasibility and advantages of using the proposed technique.

II. PROPOSED ADAPTIVE CONTROL TECHNIQUE FOR DC-AC POWER CONVERTER OF AMM

The system block diagram of DC-AC power converter of AMM is illustrated in Fig. 1. Define v_o be the output voltage, v_{ref} be the desired sinusoidal waveform, and $v_e = v_o - v_{ref}$ be the voltage error. Suppose that the switching frequency is high enough, DC-AC power converter can be considered as a constant gain, K_{pwm}. Let $e_1 = v_e$ and $\dot{e}_1 = e_2$, the error dynamic matrix can be written as

$$\begin{bmatrix} \dot{e}_1 \\ \dot{e}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} e_1 \\ e_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_{pwm}}{LC} \end{bmatrix} u + \begin{bmatrix} 0 \\ f \end{bmatrix} \quad (1)$$

where $f = -\frac{1}{LC} v_{ref} - \frac{1}{RC} \dot{v}_{ref} - \ddot{v}_{ref}$ is the system uncertainty.

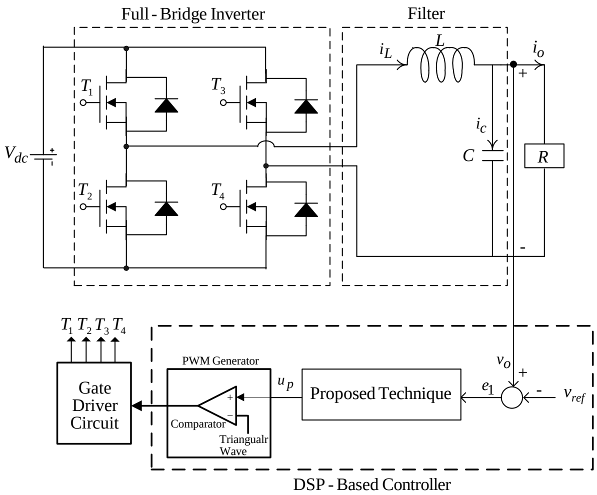

Figure 1. DC-AC power converter of AMM.

The control objective is to design a control law u_p well so that the output voltage can equal the desired reference sinusoidal. The u_p is designed below.

$$u_p = u_e + u_s \quad (2)$$

where the equivalent control, u_e is valid only on the sliding surface, and the sliding control, u_s compensates for the disturbance effects, and then the system will reach the sliding surface and converge in finite time.

To accelerate the convergence speed of the sliding phase and reaching phase, a hyperbolic tangential sliding surface is created as

$$\sigma = e_2 + \beta \tanh(\alpha e_1) \quad (3)$$

where α and β are constants.

From (3), we have

$$\dot{\sigma} = \dot{e}_2 + \frac{\alpha\beta}{\cosh^2(\alpha e_1)} e_2 \quad (4)$$

The equivalent control, u_e can be formulated as

$$\dot{\sigma}\big|_{f=0,\, u_p=u_e} = 0 \quad (5)$$

The u_s is used to suppress the system uncertainties, and can be obtained via the following inequality.

$$\sigma\dot{\sigma}\big|_{u_P=u_e+u_s} < 0 \quad (6)$$

Then, substituting (1) and (5) into (6), we have

$$u_s = -K \operatorname{sgn}(\sigma e_1),\ K > 0 \quad (7)$$

Though the (7) provides finite system-state convergence time to the origin, the chattering will occur when a highly nonlinear load is applied. Thus, one solution eliminates the chattering via ANFIS as follows. Firstly, a Takagi-Sugeno (T-S) fuzzy formation is established by the ANFIS and then we model the given training data. Thus, the ANFIS can be expressed as

$$\begin{aligned} &Rule\, i: \text{If } e_1 \text{ is } A_{i1} \text{ and } e_n \text{ is } A_{in} \\ &\quad\text{Then } u_i = p_{i1}e_1 + \ldots + p_{in}e_n + r_i \end{aligned} \quad (8)$$

where $Rule\, i$ represents the ith fuzzy rules, $i = 1, 2, \ldots j$, A_{ik} is the fuzzy set in the antecedent associated with the kth input variable at the ith fuzzy rule, and $p_{i1}, \ldots p_{in}$, r_i symbol the fuzzy resulting parameters.

Using the ANFIS, the u_p yields

$$u_p = \overline{w}_1 u_1 + \ldots + \overline{w}_j u_j \quad (9)$$

where $\overline{w}_1 = w_1 / w_1 + \ldots + w_j$ and $\overline{w}_j = w_j / w_1 + \ldots + w_j$.

Due to $u_i = p_{i1}e_1 + \ldots + p_{in}e_n + r_i$, the (9) can be rewritten as

$$\begin{aligned} u_p &= \overline{w}_1 u_1 + \ldots + \overline{w}_j u_j \\ &= (\overline{w}_1 e_1) p_{11} + \ldots + (\overline{w}_1 e_n) p_{1n} + \overline{w}_1 r_1 \\ &\quad + \\ &\quad \vdots \\ &\quad + (\overline{w}_j e_1) p_{j1} + \cdots + (\overline{w}_j e_n) p_{jn} + \overline{w}_j r_j \end{aligned} \quad (10)$$

The (10) implies that the ANFIS with the formation of five-layer and such formation can be displayed as Fig. 2.

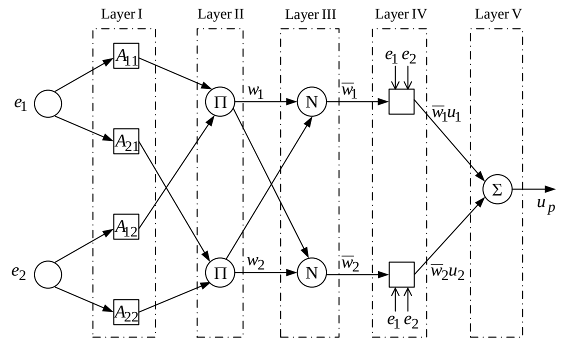

Figure 2. ANFIS formation

III. EXPERIMENTAL RESULTS

The experimental verification of the proposed technique is carried out on a DC-AC power converter with specifications shown in Table I.

TABLE I. SYSTEM PARAMETERS

Filter inductor	L=0.5 mH
Filter capacitor	C=10 μF
DC supply voltage	V_{dc}=200 V
Resistive load	R=10 Ω
Output voltage and frequency	v_o=110 V_{rms}, f=60 Hz
Switching frequency	f_s =18 kHz

We presume that the LC filter parameter values are varied from 10% ~ 200% of nominal values as the proposed system is under 10Ω resistive load; Fig. 3 and Fig. 4 show experimental output voltage waveforms with the proposed technique and the classic SMC, respectively. Owing to the elimination of the chattering, the proposed technique is insensitive to LC parameter variations than the classic SMC. To examine the transient behaviour of the DC-AC power converter of AMM, Fig. 5 shows experimental output voltage and the load current for the proposed technique with phase-controlled load. As can be seen, a fast recovery of the steady-state response and slight voltage depression can be obtained; however, the classic sliding mode controlled DC-AC power converter of AMM, shown in Fig. 6 indicates large voltage depression and slow recovery time. Therefore, the proposed technique furnishes higher tracking precision, faster convergence, better voltage compensation and greater robustness. The block diagram of the hardware implementation is represented as Fig. 7. The output voltage %THD in the face of LC variations and phase-controlled load are given in Table II.

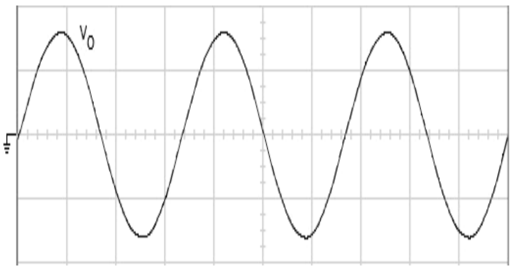

Figure 3. Experimental waveforms for the proposed technique with LC variations (100V/div; 5ms/div)

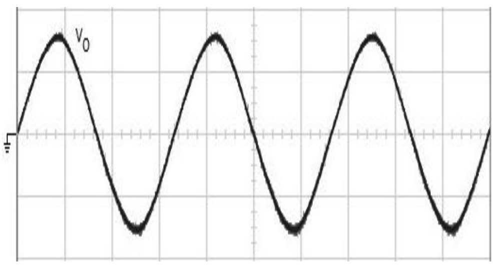

Figure 4. Experimental waveforms for the classic SMC with LC variations (100V/div; 5ms/div)

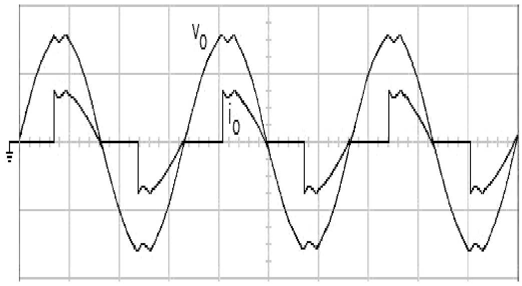

Figure 5. Experimental waveforms for the proposed technique with phase-controlled load (100V/div; 20A/div; 5ms/div)

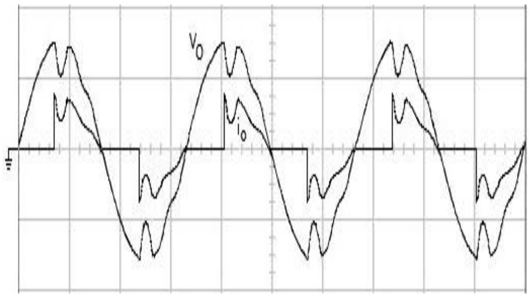

Figure 6. Experimental waveforms for the classic SMC with phase-controlled load (100V/div; 20A/div; 5ms/div)

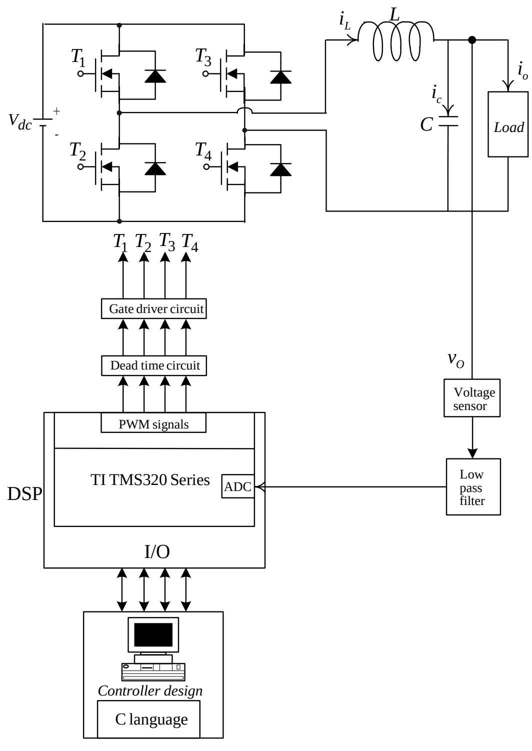

Figure 7. Block diagram of hardware implementation.

TABLE II. OUTPUT VOLTAGE %THD UNDER LC PARAMETER VARIATIONS AND PHASE-CONTROLLED LOAD

	Proposed Technique		Classic SMC	
Loads	LC Variations	Phase-Controlled Load	LC Variations	Phase-Controlled Load
%THD	0.15%	1.81%	9.42%	10.04%

IV. Conclusions

This paper develops a HTSS with ANFIS, and then applied to the DC-AC power converter of AMM so that chattering elimination, fast dynamic response and low THD output voltage can be obtained. The proposed technique not only has the robustness of classic SMC but also increases the convergence speed of the sliding phase and reaching phase, and resolves the chattering problem. The improvement in system performance has been testified via experiments, confirming the proposed technique. Compared to classic SMC, the proposed technique indeed provides the insensitivity to load interferences.

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