CURRENT CONTROL FOR PWM AC-DC CONVERTER USING SINUSOIDAL TRACKING CONTROLLER

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ABSTRCT – This paper presents a novel current control system to eliminate the steady state control error and to improve the transient charicteristics for PWM AC-DC converter. A general mathematical model of the converter that is represented as a state-space model is first established. The state-space model is used for the simulation of PWM switching converter with the proposed current control system.

The proposed sinusoidal tracking control system that does not require coordinate transformations using principle of the integral controller is described. It is proved that the steady state deviation reduces to zero through a transfer function of source current control system.

Finally, It is seen that the simulations agree with the experimental results in source current and reference of controlled ac current loop.

1. INTRODUCTION

Most AC-DC converters were diode rectifiers or phase controlled thyristor rectifiers so far. But, such rectifiers have got some problems with poor power factor and harmonic pollution. These problems can exert harmful influences upon other loads.

On the contrary, PWM AC-DC converters that have both rectifying and regenerating abilities get the merits of nearly sinusoidal source current and unity power factor.

Recently, PWM AC-DC converters are applied to an ac source side converter for driving ac motor and UPS.

As increasing interest for PWM AC-DC converters, various control strategies have been introduced[1-6]. Among these controllers, assuming that PI controller is adopted as a source current controller[7], three-phase ac components are required coordinate transformations to dc components because the PI controller can eliminate the control error completely only for the dc components. This leads to a complicated control system including coordinate transformation algorithm.

In this paper, a source current control system which is simplified and is used the principle of the integral controller is proposed.

The poles of sinusoidal signal that is the reference of source current are included in the proposed control system[8], so that the steady state error of source current can be eliminated completely without the coordinated transformation algorithm, i.e. pure current control characteristics can be obtained from the simplified control system.

2. MATHEMATICAL MODEL FOR THREE-PHASE PWM VSC

The main circuit of three-phase PWM VSC (Voltage Source Converter) is shown in Fig. 1.

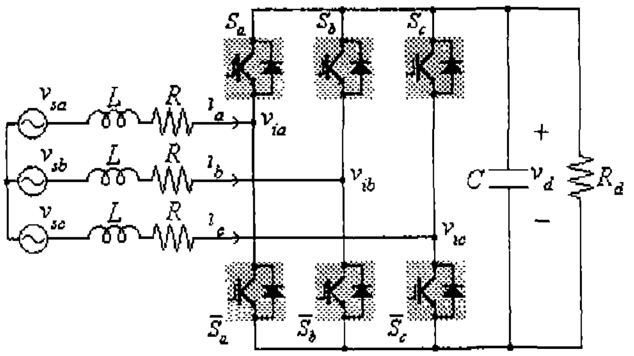

Fig. 1 Main circuit of three-phase PWM VSC

v_{sa}, v_{sb}, v_{sc} : source phase voltage

i_{sa}, i_{sb}, i_{sc} : source current

v_{ia}, v_{ib}, v_{ic} : converter input voltage

v_d : dc output voltage

L, R : ac side inductance / resistance

C, R_d : dc side capacitance / load resistance

Equation (1) and (2) can be obtained from Fig. 1.

$$L\frac{di_a}{dt} = v_{sa} - R\,i_a - v_{ia}$$
$$L\frac{di_b}{dt} = v_{sb} - R\,i_b - v_{ib} \qquad (1)$$
$$L\frac{di_c}{dt} = v_{sc} - R\,i_c - v_{ic}$$

$$C\frac{dv_d}{dt} = S_a i_a + S_b i_b + S_c i_c - \frac{v_d}{R_d} \qquad (2)$$

Where S_a, S_b and S_c are positive switching functions and $\bar{S}_a, \bar{S}_b$ and $\bar{S}_c$ are negative switching functions for each phases.

When switch is 'on' switching function is 1, and when switch is 'off' switching function is 0. Because either S_a or $\bar{S}_a$ is conducting and only one of them is allowed to conduct in any moment, i.e.

$$S_a + \bar{S}_a = 1$$

Switching functions for another two phases are also similar. Equation (1) is can be rewritten for switching function as following state-space model.

$$\dot{X} = AX + BU \qquad (3)$$

$$X = [\,i_a \;\; i_b \;\; i_c \;\; v_d\,]^T \qquad (4)$$

$$U = [\,v_{sa} \;\; v_{sb} \;\; v_{sc}\,]^T \qquad (5)$$

$$A = \begin{bmatrix} -\frac{R}{L} & 0 & 0 & -\frac{1}{L}(S_a - \frac{S_k}{3}) \\ 0 & -\frac{R}{L} & 0 & -\frac{1}{L}(S_b - \frac{S_k}{3}) \\ 0 & 0 & -\frac{R}{L} & -\frac{1}{L}(S_c - \frac{S_k}{3}) \\ \frac{S_a}{C} & \frac{S_b}{C} & \frac{S_c}{C} & -\frac{1}{CR_d} \end{bmatrix} \qquad (6)$$

$$B = \begin{bmatrix} \frac{1}{L} & 0 & 0 \\ 0 & \frac{1}{L} & 0 \\ 0 & 0 & \frac{1}{L} \\ 0 & 0 & 0 \end{bmatrix} \qquad (7)$$

where. $S_k = S_a + S_b + S_c$

The state-space model is used for the simulation of converter with the proposed current control system.

3. SOURCE CURRENT CONTROL SYSTEM

Construction of the source current control system

Assuming that the current reference I_s^* in Fig. 2 is a step input, the steady state error can be eliminated completely by employing the PI controller. Also the transient state characteristic can be improved depending on a good selection of proportional gain.

The pole of integral controller is the same as the pole of a step input reference in the PI controller, i.e. the same poles as the reference are included in a control system in order to eliminate the steady state error of source current.

However, the reference I_s^* is sinusoidal signal in this control system, thus the proposed sinusoidal tracking control system is constructed with the same poles as sinusoidal reference as following Fig. 2

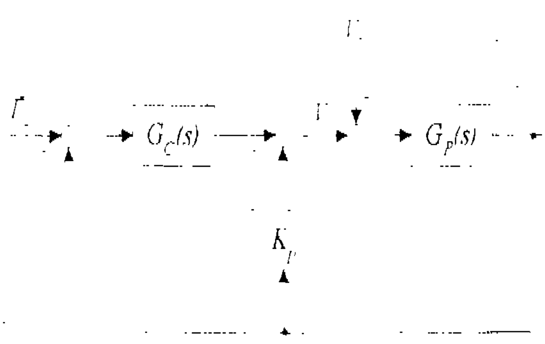

Fig. 2 Block biagram of current control system

$G_C(s)$ is the transfer function with the same poles as the sinusoidal reference, K_P is proportional gain, and $G_P(s)$ is ac side circuit transfer function with L and R. I_s, I_s^* are source current and the reference. V_s, V_i are source phase voltage and converter input voltage.

Transfer function of the source current control system

In Fig. 2, each block transfer function is as follows.

$$G_C(s) = \frac{K_C \cdot \omega^2}{s^2 + \omega^2} \quad (8)$$

$$G_P(s) = \frac{1}{Ls+R} \quad (9)$$

Where ω is the angular frequency of source current reference.

In order to verify the steady state error in the proposed control system, the transfer function from I_s^* to I_s is as follows.

$$\frac{I_s(s)}{I_s^*(s)} = \frac{-G_C(s) \cdot G_P(s)}{1-\{G_C(s)+K_P\} \cdot G_P(s)} \quad (10)$$

Substituting (8), (9), and $s=j\omega$, so as to verify the characteristc for source frequency into (10), the result is as follows.

$$\frac{I_s(s)}{I_s^*(s)} = 1 \quad (11)$$

This means that the source current completely tracks the reference without the steady state error. Therefore, good current control characteristics can be obtained from the simplified control system, which does not need coordinated transformation algorithm.

Realization of the controller

The LC equivalent circuit is introduced in order to realize (8). The equivalent circuit as shown in Fig. 3.

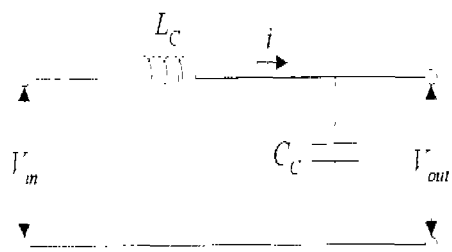

Fig. 3 LC equivalent circuit

Substituting input u for the equivalent circuit input V_{in} and output y for the circuit output V_{in}. From Fig. 3, the differential equations can be obtained as follows.

$$u = L_C \frac{di}{dt} + y \quad (12)$$

$$y = \frac{1}{C_C} \int i \, dt \quad (13)$$

Assuming that $L_C = C_C = 1/\omega$, (14) is obtained from (12), (13). Where ω is the same as the source angular frequency

$$\frac{d^2 y}{dt^2} + \omega^2 y = \omega^2 u \quad (14)$$

Assuming that T_s is sampling period, (14) is can be rewrite as follows.

$$\frac{\frac{y(n+1)-y(n)}{T_s}-\frac{y(n)-y(n-1)}{T_s}}{T_s}+\omega^2 y(n+1)=\omega^2 u(n) \qquad (15)$$

Where $n-1$, $n+1$ are each a former time of n and a later time of n. The $(n+1)th$ output $y(n+1)$ is derived from a $(n-1)th$ output $y(n-1)$, a $(n)th$ output $y(n)$ and a $(n)th$ input $u(n)$ as follows.

$$y(n+1)=\frac{1}{1+\omega^2 T_s^2}\left\{2y(n)-y(n-1)+\omega^2 T_s^2 u(n)\right\} \qquad (16)$$

4. SIMULATIONS

To verify the validity of the proposed control strategy, simulation studies were pursued before experimental work as follows.

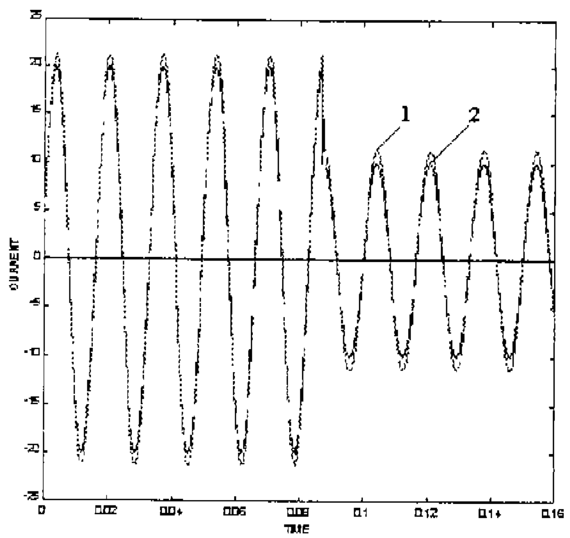

Fig. 4 Source current and reference with PI controller
(1 : Source current, 2 : Reference)

The source current and its reference with PI control are shown in Fig. 4. The steady state error remain because PI controller is used without the coordinated transformations for three-phase ac component and the steady state error is still existent after changing reference amplitude 20[A] to 10[A] at 0.0875[sec].

In Fig. 5, the source current and its reference with proposed control are also shown. The source current completely tracks reference without the steady state error, and for a transient changing reference amplitude 20[A] to 10[A] at 0.0875[sec], the steady state error is completely eliminated about two periods later.

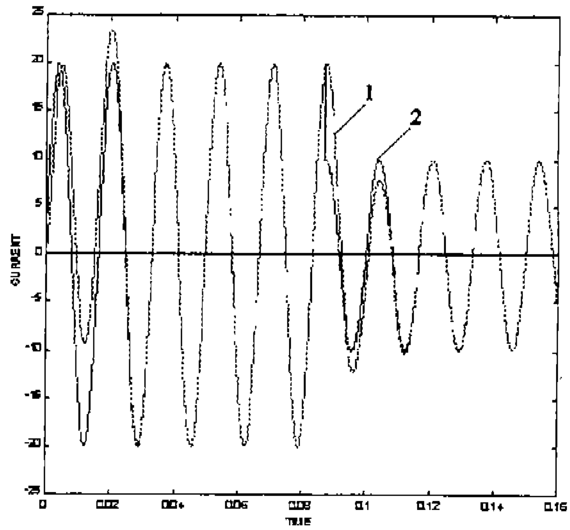

Fig. 5 Source current and reference with proposed controller
(1 : Source current, 2 : Reference)

It is verified that good source current control characteristics can be obtained as the proposed control system, which does not need coordinated transformation algorithm from simulation.

5. EXPERIMETAL RESULTS

The control block diagram of PWM VSC system is shown in Fig. 6.

The amplitude of the current reference I_m^* is producted in comparision dc voltage reference v_d^* with dc voltage v_d to control dc output voltage. After the voltage controller, the current reference i_s^* is producted by a multiplier with the current reference amplitude I_m^* and the unity sinusoidal wave from utility. The producted current reference i_s^* is used as a control signal.

In Fig. 6, the current controller consists of a proportional gain K_P, a transfer function $G_C(s)$ to eliminate the state steady error with the same poles as sinusoidal reference.

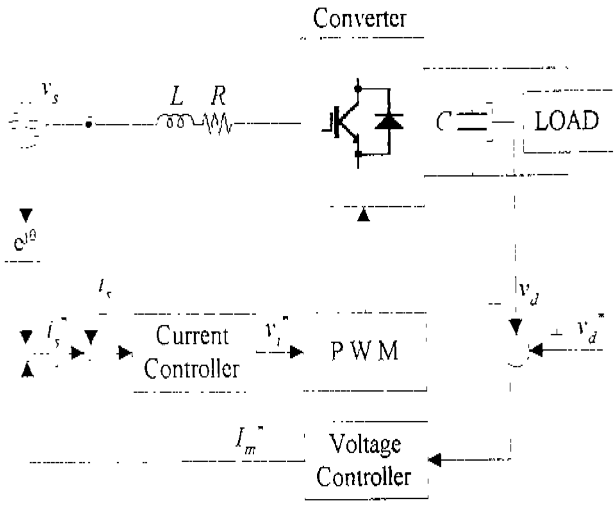

Fig. 6 Block diagram of converter system

The parameters which were used in experimental work as follows.

source phase voltage : $v_s = 57.7[V]$ / $60[Hz]$

ac side inductance : $L = 6.5[mH]$

ac side resistance : $R = 0.5[\Omega]$

dc output voltage : $v_d = 200[V]$

dc side capacitance : $C = 500[\mu F]$

switching frequency : $f_s = 1.8[kHz]$

Where source phase voltage v_s is RMS value.

The phase voltage v_{sa} and the source current i_{sa} are shown in Fig.7. It is seen that the source current is nearly sinusoidal with unity power factor

Fig. 8 shows dc output voltage v_d and source current i_{sa} for a sudden change of load resistance from 15[Ω] to 30[Ω]. After a sudden change of load, dc output voltage and source current are well reached to the steady state.

In other words, the source current as well as dc output voltage are well controlled in converter system with proposed control.

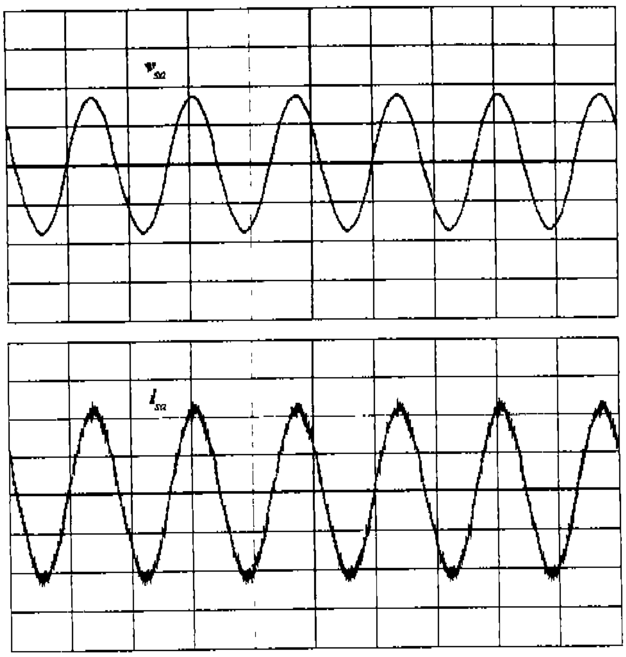

Fig. 7 Source phase voltage and source current (v_{sa} : 50V/div, i_{sa} : 10A/div, t : 10ms/div)

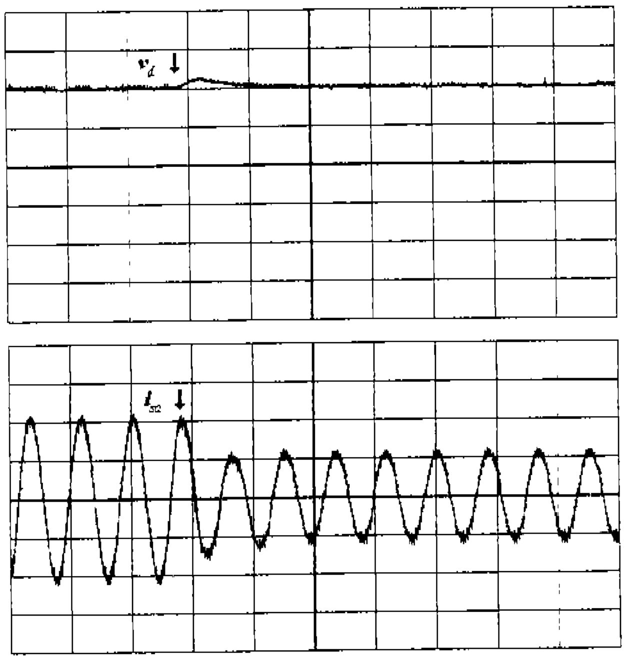

Fig. 8 DC output voltage and source current for a sudden change of road resistance (v_d : 100V/div, i_{sa} : 10A/div, t : 20ms/div)

6. CONCLUSION

In this paper, it has been proved that the steady state deviation reduce to zero through a transfer function for source current control system. And, not only the steady state characteristics but also the transient state characteristics were verified from simulation and experimental work.

The pole of integral controller is the same as the pole of step reference in the PI controller. According to this control strategy, the proposed sinusoidal tracking control system is constructed. This current control model is realized from differential equations for the LC equivalent circuit. The control system can eliminate the steady state error of source current together with dc output voltage for a sudden change of load with little variation. Thus, effective control characteristics can be obtained by the proposed simple control system.

7. REFERENCES

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