A Novel Voltage Fluctuation Generating Circuit Topology and Control Strategy

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***Abstract*-- A novel voltage fluctuation and flicker generating main circuit topology is proposed in this paper, combined with passive and active to realize voltage fluctuation and flicker. The fundamental frequency power is supplied by system source and the other frequency fluctuation power is supplied by active components, so the capacitor of generator is easy to realize larger because of lower active loss. Full-bridge diode rectifier is adopted to maintain the stable DC-bus voltage, the later inverter is controlled by instantaneous value voltage and current double closed-loop to make sure good static and dynamic performance. The inverter output two frequency voltage waveforms, and added to fundamental frequency sinusoidal voltage waveform by transformer so that the typical sinusoidal modulation voltage fluctuation and flicker waveform is obtained. The simulation model is set up on the platform of Matlab/Simulink. Finally, the simulation and experimental results show that the proposed main circuit and control strategy is feasible and efficient.**

Key words—power quality; voltage fluctuation and flicker; inverter; double closed-loop control; sinusoidal pulse width modulation

I. INTRODUCTION

In modern power system power loads become more and more complex, especially the technology of power electronic is widely used, which bring forth the power quality problem of voltage and current harmonic, voltage fluctuation and flicker et al. The problem became more and more seriously, that brought new challenge to the power system stability and security. In addition, the unstable energy gird to the electric network could cause system voltage fluctuation and flicker, wind energy, solar energy and so on. The power quality generator and regulator became more and more important in power system, because they are helpful for economical efficiency and improve the power quality. That is hardly to confirm where or when the voltage fluctuation and flicker occurrence, so that enhanced difficulty to research the reason and performance of the voltage fluctuation and flicker. So, that is very necessary to research and design a voltage fluctuation and flicker generator. That became easy to research power system applications and power loads under voltage fluctuating and flicker with the generator.

Now the power electronic applications composed of full controlled semiconductor device is widely researched, but hardly see papers reporting on the voltage fluctuation and flicker generating application researched and designed. Paper [10] researched a full power voltage disturbance generating application, the three-phase half-bridge inverter output all voltage disturbance waveform. But this paper proposed a novel series voltage fluctuation and flicker generating main circuit topology and its control strategy. The active and passive components hybrid working mode is adopted, main power of the application is provided by passive system power source and fluctuating power is provided by single-phase full-bridge inverter. The fluctuating power is very small only 10% rating capacitor, so the loss of application could be small, it good to enhance the rating capacitor of the application. The inverter is controlled by instantaneous value voltage and current double closed-loop to ensure the static and dynamic performance of output waveform. The simulation model is set up on the platform of Matlab/Simulink, and the 1kVA prototype is designed and made. Finally, the simulation and experimental results show that the proposed main circuit and control strategy is feasible and efficient.

II. MAIN CIRCUIT TOPOLOGY OF VOLTAGE FLUCTUATION AND FLICKER GENERATOR

Aim at the function of voltage fluctuation and flicker about the voltage disturbance generating application, the main circuit topology of voltage fluctuation generating is researched shown in figure.1. The main circuit is composed of series active components and passive commercial power. The active components is composed of single-phase full-bridge diode rectifier D_1~D_4, single-phase full-bridge inverter S_1~S_4, DC-bus capacitor, low pass filter Lf and C_f, transformer T.

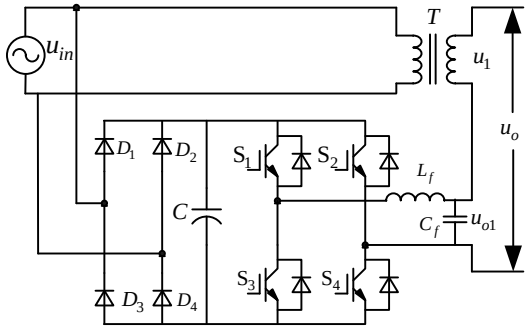

Fig. 1 Main circuit of voltage fluctuation generator

This work was supported byProject Supported by National Mega-projects of Science and Technology for the 11th Five-year Plan (2007BAA12B03)

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978-1-4244-2235-7/09/$25.00 ©2009 IEEE

III. BASIC PRINCIPLE OF VOLTAGE FLUCTUATION GENERATING APPLICATION

The stable DC-bus voltage is provided by the full-bridge diode rectifier for inverter working, full-bridge inverter is controlled by voltage and current instantaneous value double closed-loop. The control strategy ensured the inverter output good waveforms. The inverter output two frequency voltage waveforms, the added fundamental frequency voltage provided by system, then the fluctuation voltage is obtained on the load.

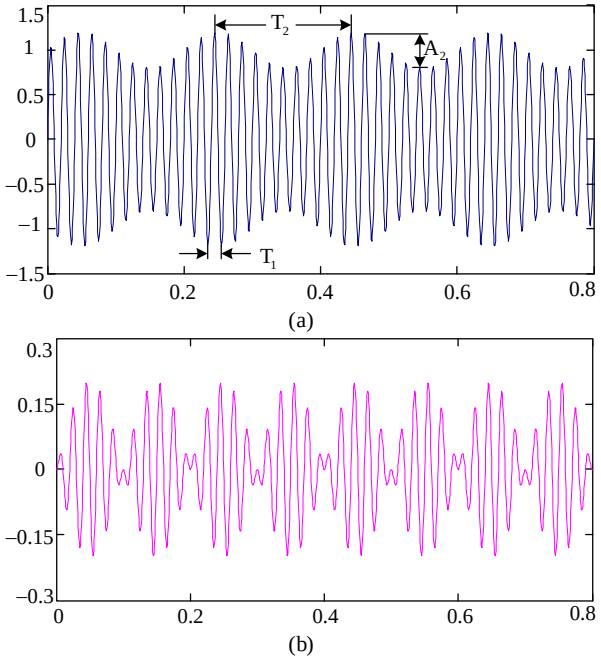


Fig. 2 Typical voltage fluctuation waveform

Typical voltage fluctuation and flicker waveform shown in figure 2(a), the mathematical expression as following expression (1),

$$u = (A_1 + A_2 \sin(\omega_2 t))\sin(\omega_1 t) \quad (1)$$

According to expression (1), the RMS of voltage fluctuation waveform is obtained as following expression (2),

$$u_{rms} = A_1 + A_2 \sin(\omega_2 t) \quad (2)$$

Where ω1 is the fundamental voltage frequency, ω2 is the low frequency voltage fluctuation and flicker frequency, the control strategy of the paper is make the inverter output modulation voltage u2, as expression (3),

$$u_2 = A_2 \sin(\omega_2 t) \times \sin(\omega_1 t) \quad (3)$$

Expression (3) could be deduced expression (4), as following,

$$u_2 = -\frac{A_2}{2}\left[\cos(\omega_1 + \omega_2)t - \cos(\omega_1 - \omega_2)t\right] \quad (4)$$

Added on fundamental frequency voltage u1 as expression (5),

$$u_1 = A_1 \sin(\omega_1 t) \quad (5)$$

The output voltage u_o on load is fluctuated, shown as the following expression (6),

$$u_o = A_1 \sin(\omega_1 t) - \frac{A_2}{2}\left[\cos(\omega_1 + \omega_2)t - \cos(\omega_1 - \omega_2)t\right] \quad (6)$$

IV. CONTROL STRATEGY AND KEY PARAMETERS DESIGN

A Analysis the control strategy of inverter

The most important of the novel voltage fluctuation generator main circuit is the control strategy of positive components. In other words, the core is the control strategy of the full bridge inverter. The conventional inverter only output single frequency voltage waveform, but in this application it should output two frequency voltage waveforms, typical waveform as figure 2(b) showed. In addition, the inverter needs good static performance, also good dynamic performance. So the voltage and current instantaneous value double closed-loop controlled method is adopted in the inverter, the control blocks as the figure 3 showed.

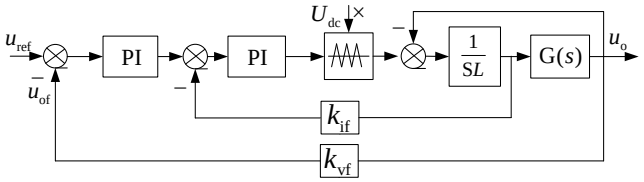
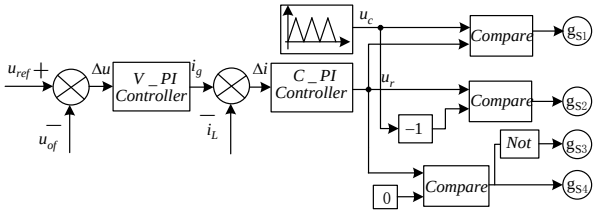
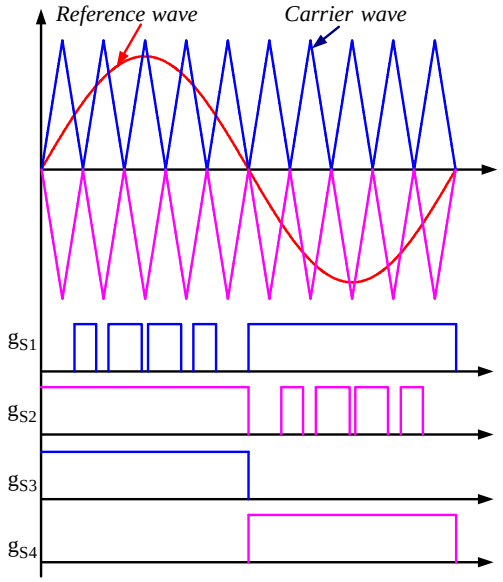


Fig. 3 Closed-loop control blocks of inverter

The inverter main circuit structure is full-bridge, the modulate strategy is single sinusoidal pulse width modulation (SSPWM). The reference voltage uref subtract feedback voltage uof, sent the voltage error signal Δu to voltage PI controller, the output signal as the reference current ig, then ig subtract feedback inductor current iL, sent the current error signal Δi to current PI controller, the output signal ur as reference wave. The SSPWM control strategy shown in figure 4 (a) and (b).



(a)



(b)

Fig. 4 SSPWM modulation strategy

B LC low pass filter design

From expression (3) can obtain the inverter output two frequency voltage, one frequency is f_2, $f_2=(\omega_1+\omega_2)/2\pi$, the other frequency is f_3, $f_3=(\omega_1-\omega_2)/2\pi$. According to the demanded voltage fluctuation frequency is form 0.5Hz to 25Hz, then the inverter output voltage frequency changes between 25Hz and 75Hz, so the LC low pass filter design must fit for this frequency range and make sure the output voltage hardly reduced.

The LC low pass filter shown in figure 5(a), and transfer function shown as expression (7),

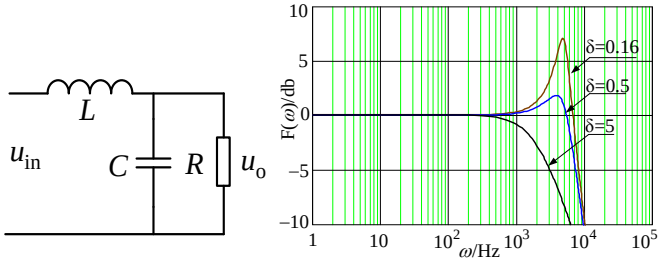
$$\frac{u_o}{u_{in}}(j\omega)=\frac{\omega_0^2}{-\omega^2+j2\delta\omega+\omega_0^2} \tag{7}$$

According to expression (7), could obtain the amplitude-frequency function shown as expression (8),

$$F(\omega)=\left|\frac{u_o}{u_{in}}(j\omega)\right|=\frac{\omega_0^2}{\sqrt{\left(\omega_0^2-\omega^2\right)^2+\left(2\delta\omega_0\omega\right)^2}} \tag{8}$$

According to expression (8), the amplitude-frequency curve shown in figure 5(b), so the parameters of LC low pass filter could be calculated. Where, δ is the filter damping parameter, ω0 is the filter resonant angular frequency, as follow:

$$\delta=\frac{1}{2R}\sqrt{\frac{L}{C}}\ 、\ \omega_0=\frac{1}{\sqrt{LC}}.$$



(a) (b)

Fig. 5 Low pass filter and amplitude-frequency curve

V. SIMULATION ANALYSIS

The simulation model is set up on the platform of Matlab/Simulink, the control strategy is researched by simulation. The key simulation parameter as the table 1 showed.

Table.1 KEY SIMULATION PARAMETER OFTHE VOLTAGE FLUCTUATION AND FLICKER GENERATOR

System voltage u_S	220V
Transformer ratio *n*	1：1
Switch frequency *f*	10kHz
Low pass filter	L=1mH，C=30μF
Voltage loop PI parameter	k_{VP}=2、k_{VI}=0.001
Current loop PI parameter	K_{IP}=5、k_{II}=0.0008

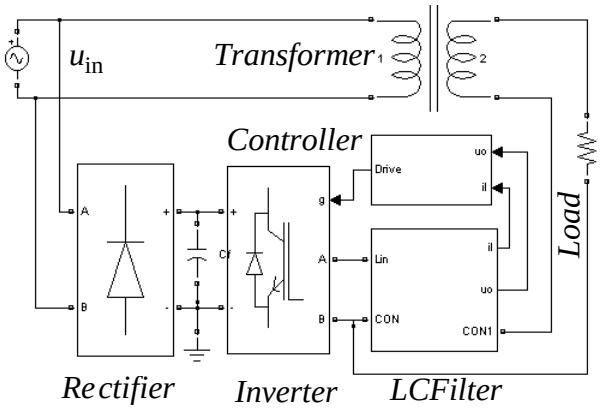
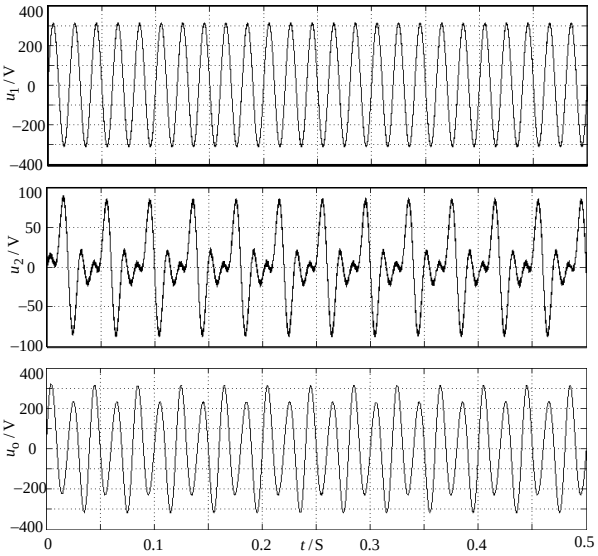
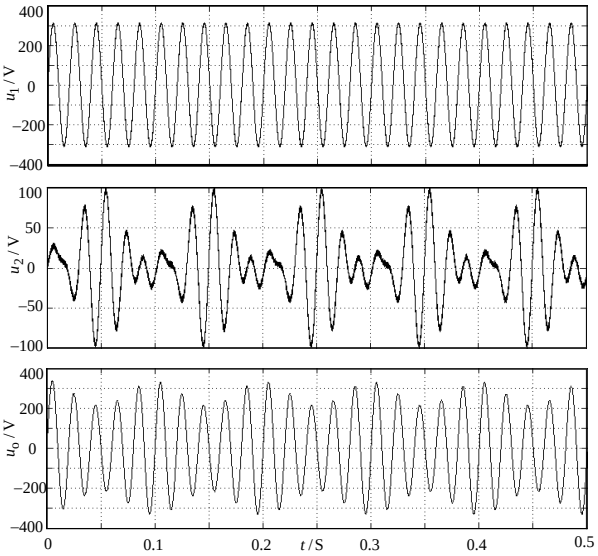


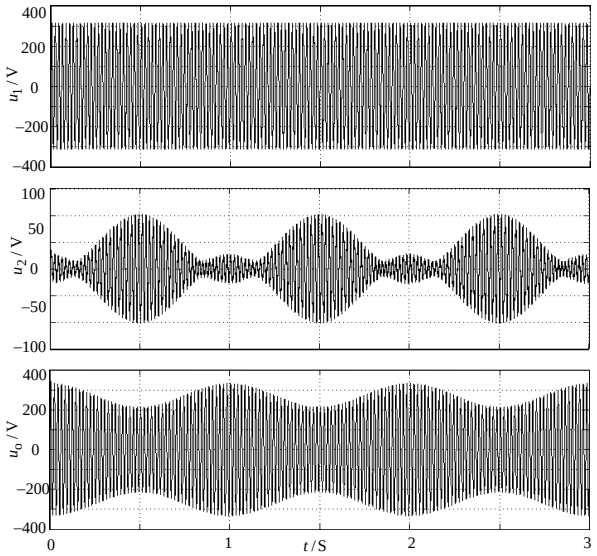
Fig. 6 Simulation model



(a) 25Hz



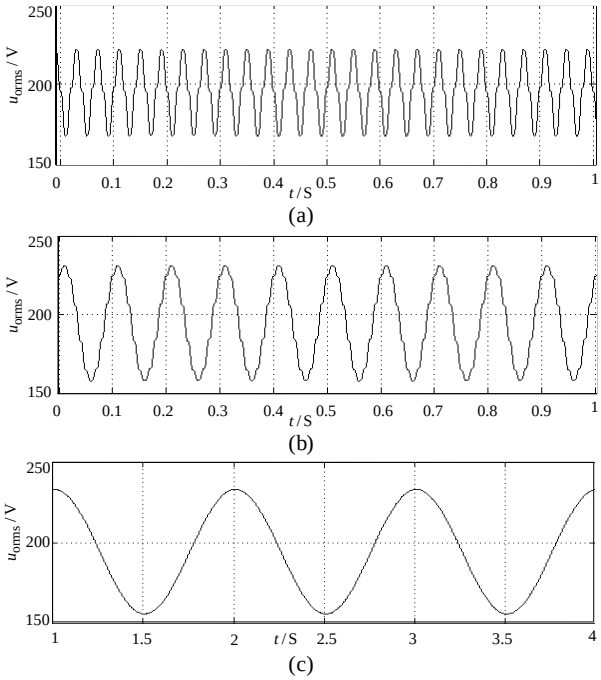
(b) 10Hz



(c) 1Hz

Fig. 7 Simulation waveform of voltage fluctuation

Figure 7 (a), (b) and (c) stand for the simulation voltage fluctuation instantaneous value waveforms, the low fluctuation frequency is 25Hz, 10Hz and 1Hz respectively. Waveform u1 is the system voltage, u2 is the inverter output voltage and uo is the added voltage on the load. The simulation result shows that the proposed control strategy could make the application output good voltage fluctuating waveform, meanwhile it is feasible and efficient.



(a)

(b)

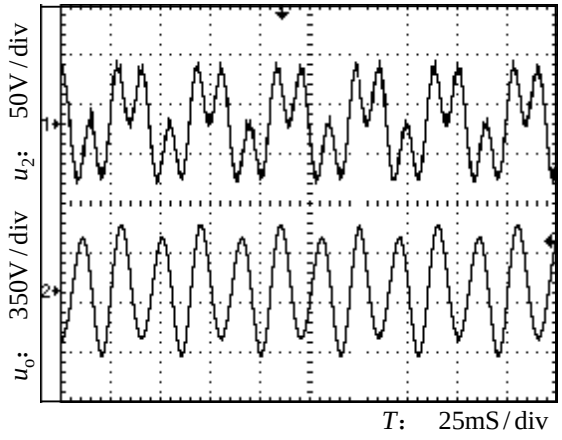
(c)

Fig. 8 RMS of fluctuate voltage

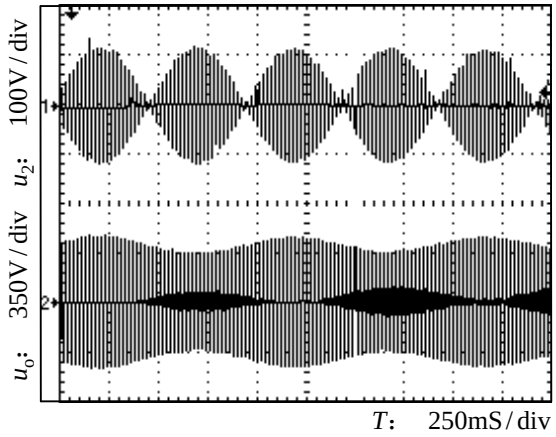
The simulation voltage RMS is showed as Figure 8 (a), (b) and (c), the RMS of output voltage has low frequency is 25Hz, 10Hz and 1Hz, the RMS of fluctuation voltage is 10% of rating voltage.

VI. EXPERIMENTAL RESULTS

The controller of Voltage fluctuation generator prototype is composed of high performance DSP (TMS320F2812), which finish voltage and current sampling, PI calculating and PWM signal generating. The key parameters of application as follows, filter inductor L=1mH, filter capacitor C=30μF, switch frequency f=10kHz, output voltage u_o=311sin(100πt) added low frequency (1~25Hz) sinusoidal voltage fluctuation and flicker, the rating power P=1000VA

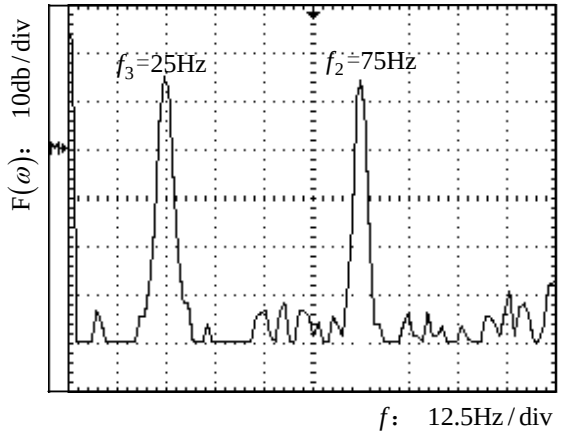


(a) 25Hz

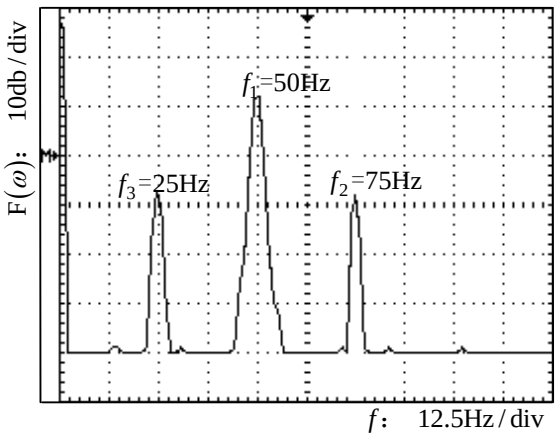


(b) 1Hz

Fig. 8 Voltage fluctuation experimental waveform



(a)



(b)

Fig. 9 Voltage fluctuation frequency spectrum-gram

Figure 8 (a), (b) and (c) stand for the experimental voltage fluctuation instantaneous value waveforms, the 25Hz low frequency voltage fluctuation and flicker waveform shown in figure 8 (a), the full-bridge inverter output the modulation waveform u_2, added the fundamental frequency sinusoidal voltage waveform, then the fluctuating voltage u_o is obtained on the load side. The fluctuate frequency 1Hz shown in figure 8 (b). So, the experimental waveform verified the main circuit topology and control strategy is feasible and efficient for the voltage fluctuation and flicker generating.

The frequency spectrum-gram of 25Hz low frequency voltage fluctuation and flicker shown in figure 9, the inverter output voltage waveform frequency spectrum-gram shown in figure 9 (a), it contains 25Hz and 75Hz two frequency voltage. The fluctuation and flicker voltage waveform frequency spectrum-gram on the load shown in figure 9 (b), it contains 25Hz, 50Hz and 75Hz three frequency voltage. The above waveform shows that the harmonic is the inner reason to cause the fluctuation and flicker voltage.

VII. CONCLUSIONS

The proposed voltage fluctuation and flicker generating main circuit is a novel topology, has the advantages as follows:

(1) The hybrid mode of active and passive is adopted, the main fundamental frequency power is provided by system source directly. Then the other frequency power is provided by inverter, so the generator efficiency is high and easily to realize larger capacitor output.

(2) Double closed-loop control strategy of voltage and current instantaneous value is adopted in inverter control to make the inverter output voltage THD lower and improve the static and dynamic performance.

(3) The main circuit structure of the generator is simple, less power devices needed and has the high security.

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VIII. BIOGRAPHIES

Renzhong Shan was born in Ningbo, china, in 1982. From 2000 to 2004, he studied in Zhejiang University of science and technology, Zhejiang province, and received the B.S. From 2004 to 2007, he studied in Nanjing University of Aeronautics and Astronautics, Jiangsu province, and received the M.S.Since 2007, he has been in North China Electric Power University, where he is a post-doctor student in School of Electrical Engineering, mainly engaging in research of power electronics, power quality and their control systems.

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