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A Single Phase Seven-level Grid-connected inverter Based On Three Reference SPWM Strategy

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Abstract—**This paper introduces a seven level grid connected system based on the Three Reference SPWM (TRSPWM) strategy and a Quasi PR current controller has a good output performance with a fast response and compensation for the low order harmonics in grid. With the multilevel output voltage and a high tracking current strategy with a low-order harmonic compensator, the grid connected system could operate properly in a polluted grid with low order harmonic. The simulation based on MATLAB verify the proposed the accuracy and feasibility of the proposed scheme.**

Keywords: Seven level inverter; Multi references SPWM; Quasi PR controller

I. INTRODUCTION

The high performance of the grid connected inverters has a critical effect on renewable energy system, which determines the operation efficiency and quantity of the whole system[1-3]. In reality, the grid connected system usually will operate interfacing the distorted grid voltage with low order harmonics. The multilevel converters which could offer a small voltage steps and high resolution output voltage waveforms, and employing a current control strategy with a high tracking performance could be a good solution for polluted grid environment.

With the advantages over the two-level converters, improved voltage waveform on the AC side, smaller filter size, lower electromagnetic interference and lower acoustic noise, multi-level converter attracts more and more attentions[3]. At present, Neutral Point diode-clamped [4], flying capacitor [5] and cascaded H-bridge [6] are applied commonly. Among them, the diode-clamped inverter has fewer switching components than other topologies. Accordingly, various SPWM schemes for single phase NPC inverter have been proposed. Multi carriers multi-level SPWM strategy is used widely, but it is not easy to implement the carrier overlapped multilevel SPWM. A three reference modulations based seven-level SPWM scheme is presented in [7], which can implement seven-level SPWM waveform only with one timer. However, because it used the same reference modulations in positive and negative half cycles, the compare logics between the three half cycles and carrier are all need inversed. In [8], a half cycle wave inversed based dual reference modulation three-level SPWM (TLSPWM) scheme is proposed, which can be applied in DSP system simply.

On the other hand, high tracking current control strategies are implemented in grid connected system. Among them, the traditional PI control with a feedforward path is a popular simple method, however there exists the possibility of the distorting the line current caused by background harmonics introduced along the feedforward path if the grid voltage is distorted [9]. A repetitive control is employed to interface the harmonic in grid, and the repetitive controller has a good rejection to the harmonics but with slow dynamics. [10] use a deadbeat control which has a fast response and stability in digital controllers properly, but the performance depends much on the precise system model effected by the system parameters easily. In [11], a Quasi-PR controller with a compensation controller is employed, and the scheme can be achieved simply with a good rejection to selective low order harmonics.

Aiming at achieving a high-performance grid-connected system with a high current tracking ability interfacing the polluted grid with low order harmonics, this paper introduces a single phase simplified multi-level grid-connected system employing a Quasi-PR current controller with harmonic compensation. The paper is organized as follows. Section II introduces a seven level inverter based on a three reference SPWM strategy. In section III, the current control strategy with a Quasi-PR controller will be analyzed. In section IV, the results of the simulation of the proposed grid-connected system employing a PR current control are presented. Finally, Section V gives the conclusion.

II. PRINCIPLE OF SEVEN LEVEL INVERTER TRMS-SPWM CONTROL

The schematic diagram of single-phase seven-level converter is shown in Fig. 1. The dead time should be set between two complementary switches, V1 and V4, V2 and V5, V3 and V6, V7 and V8 respectively. To implement seven-level SPWM with dead time only using one DSP chip, the TRSPWM scheme is employed, its principle is shown in Fig.2. Three reference modulations compare with the same carrier.

To obtain seven-level SPWM waveform without inverting the compare logic of modulation and carrier, the three reference modulations are all inverted and offset with different DC values (related with the amplitude of carrier) in their negative half cycles. The comparison result of u_{r1} and carrier is as the control signal of V1, which logic inversion is as the control signal of V4. The comparison result of u_{r2} and carrier is as the control signal of V2, and its logic inversion is as the control signal of V5. The comparison result of u_{r3} and carrier is as the control signal of V3, and its logic inversion is as the control signal of V6. And in positive half cycle, the V8 is on, and the V7 is off. In negative half cycle, the V8 is off and V7 is on.

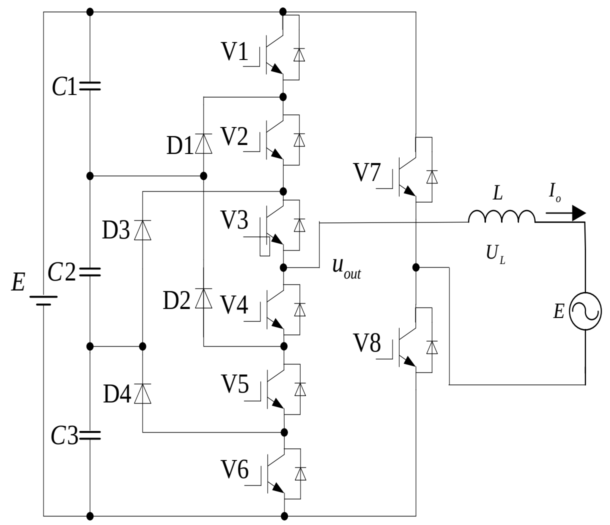

Figure 1. Schematic diagram of eight switches seven-level converter

The functions of the three reference modulations are derived as follows. Assuming the amplitude of carrier is U_{tr}, and the normal reference modulation is

$$u_{nom} = U_{nom}\sin(\omega t) \tag{1}$$

Where U_{nom} and ω are the amplitude and angle frequency of normal reference modulation respectively.

The function of u_{r3} in positive half cycle u_{r3p} has the same format with the normal one.

The function of u_{r1} in positive half cycle is

$$u_{r1p} = U_{nom}\sin(\omega t) - 2U_{tr} \tag{2}$$

The function of u_{r1} in negative half cycle is

$$u_{r1n} = U_{tr} - U_{nom}\sin(\omega t) \tag{3}$$

The function of u_{r2} in positive half cycle is

$$u_{r2p} = U_{nom}\sin(\omega t) - U_{tr} \tag{4}$$

The function of u_{r2} in negative half cycle is

$$u_{r2n} = 2U_{tr} - U_{nom}\sin(\omega t) \tag{5}$$

The function of u_{r3} in negative half cycle is

$$u_{r3n} = 3U_{tr} - U_{nom}\sin(\omega t) \tag{6}$$

The amplitude modulation ratio of the proposed TRMS-SPWM scheme is

$$m = U_{nom} / 3U_{tr} \tag{7}$$

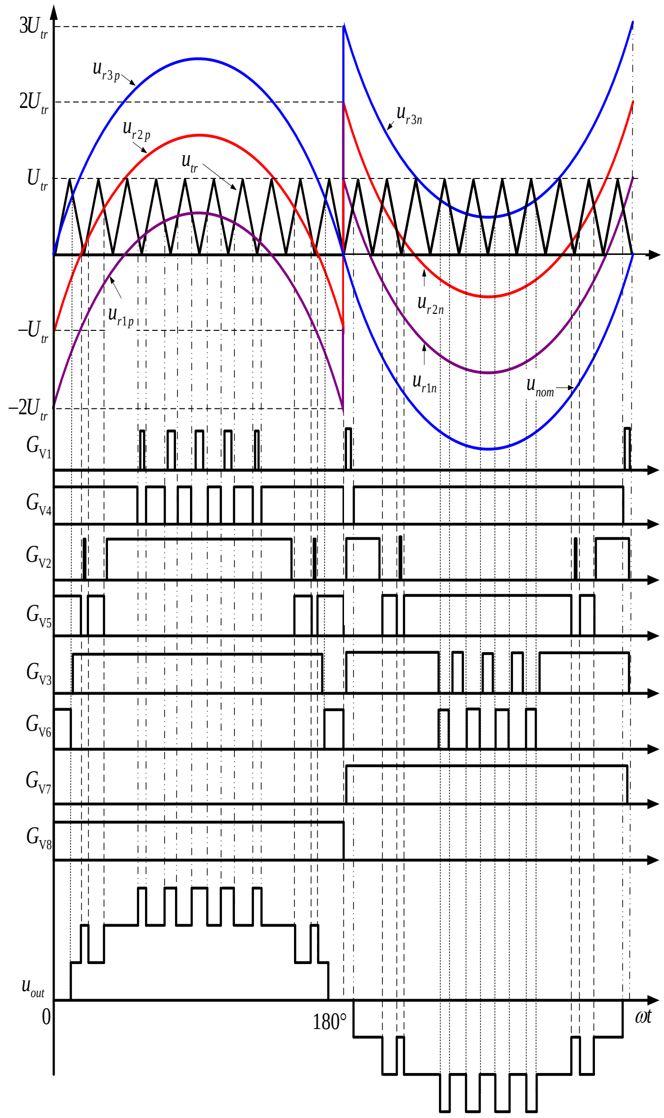

Figure 2. Schematic diagram of proposed seven-level SPWM scheme

III. SYSTEM CURRENT CONTROL STRATEGY

The basic functionality of the PR controller is to introduce an infinite gain at a selected resonant frequency for eliminating steady state error at certain frequency. The transfer function of PR is

$$G_{PR}(s) = K_P + \frac{K_R s}{s^2 + \omega_0^2} \tag{8}$$

However, the bandwidth of traditional PR controller is low, the paper adopts a Quasi PR controller, and the transfer function of Quasi PR controller is:

$$G_{QPR}(s) = K_P + \frac{K_R \cdot 2\omega_c s}{s^2 + 2\omega_c s + \omega_0^2} \tag{9}$$

where, K_P, K_R are the proportional and resonant coefficient respectively, ω_0 is the resonant frequency (set as grid frequency in a grid connected system), ω_c is the cut-off frequency.

The bode plots of PR and Quasi PR is shown in Fig. 3 respectively. The Quasi-PR controller inherits the advantages of the traditional PR controller. Furthermore, the Quasi-PR controller still can achieve zero steady-state error, when the grid frequency offset happens, which improves the drawbacks of PR controller.

In real system, the grid is commonly polluted with low order harmonics such as 3th, 5th, 7th harmonic, causing that the grid current also contains certain harmonics, which influence the performance of the system and lead to a poor current THD.

In order to solve the problem, a harmonic compensator can be added to QPR controller, the transfer function of harmonic compensator is:

$$G_{HC}(s) = K_{HP} + \sum_{h=3,5,7} \frac{K_{HR} \cdot 2\omega_{hc} s}{s^2 + 2\omega_{hc} s + (h\omega_0)^2} \tag{11}$$

where, h is the order of harmonic. K_{HP}, K_{HR} and ω_{hc} are the proportional coefficient, resonant coefficient and cut-off frequency of the respective harmonic compensation controller.

The bode plot of Quasi PR controller with a harmonic compensator is shown in Fig. 4. The block scheme of the current loop with a Quasi PR controller with a harmonic compensator is depicted in the Fig. 5.

The open loop transfer function of the system is:

$$G(s) = (G_{QPR}(s) + G_{HC}(s)) \cdot K_{PWM} \cdot G_d(s) \cdot G_f(s) \tag{12}$$

The control scheme of the grid connected system is shown in Fig. 6. The system employs a seven level inverter, employ a current control loop, the current reference is calculated based on the phase from PLL, and the compared result between the sampling instantaneous value of grid current and reference is processed by the Quasi PR controller, then the output of current controller is given as the input of TRSPWM generator to produce the PWM signals to drive the seven level grid connected inverter.

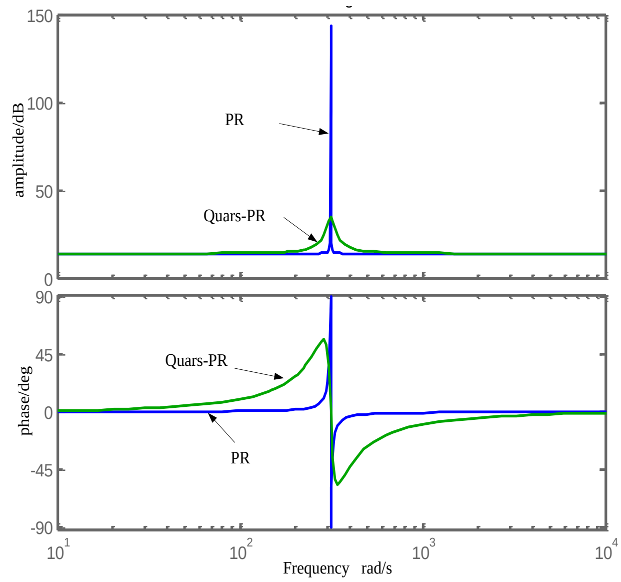

Fig. 3. Bode plot of PR and Quasi PR controller

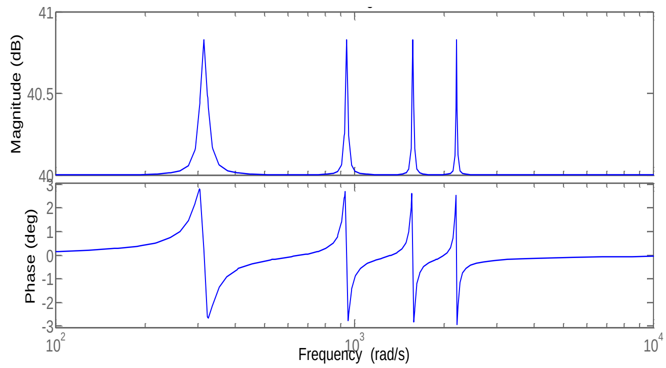

Fig. 4. Bode plot of Quasi PR controller with a harmonic compensator

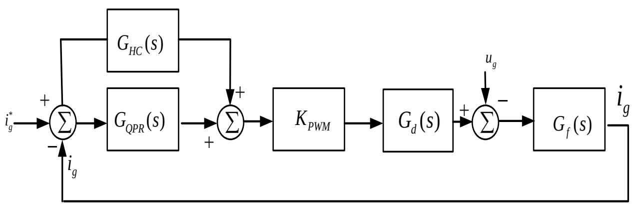

Fig. 5. Control strategy of grid connected system

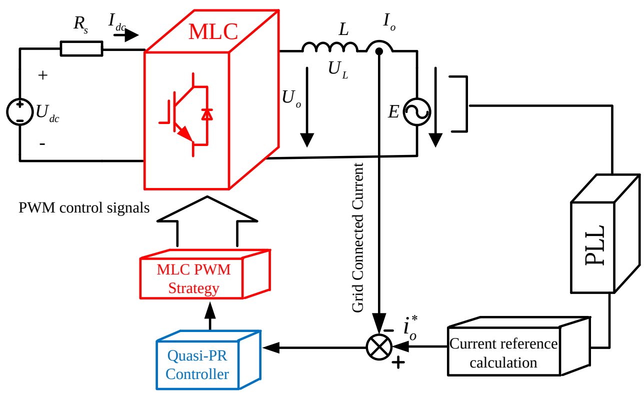

Fig. 6. Control strategy of grid connected system

IV. SIMULATION RESULTS

To verify the feasibility of the seven level grid connected system based on TRSPWM and Quasi PR controller with a harmonic compensator, the simulation model based on MATLAB/Simulink is made. The parameters of the simulation model are shown in table.1.

TABLE I
PARAMETERS OF THE SEVEN LEVEL GRID CONNECTED SYSTEM

Grid side inductor	5mH
Carrier frequency	10khz
Single phase grid voltage	220V
DC supply voltage	450V
DC capacitor	5000uF

The simulation result of TRSPWM strategy is shown in Fig.7 to Fig.9. The Fig7 is the half-circle-inverse three references, and Fig.8 shows the PWM signals for driving IGBT. Fig.9. shows the multilevel output of inverter and the grid voltage.

Then, in Fig.10 to Fig. 13 are the waveforms of the grid current and THD. In Fig.10, the grid current tracks the current reference with a fast response. In Fig. 11 the waveform of grid current in a distorted grid is shown, and in Fig. 12 and Fig. 13 are the current THD without a compensator and with compensator respectively.

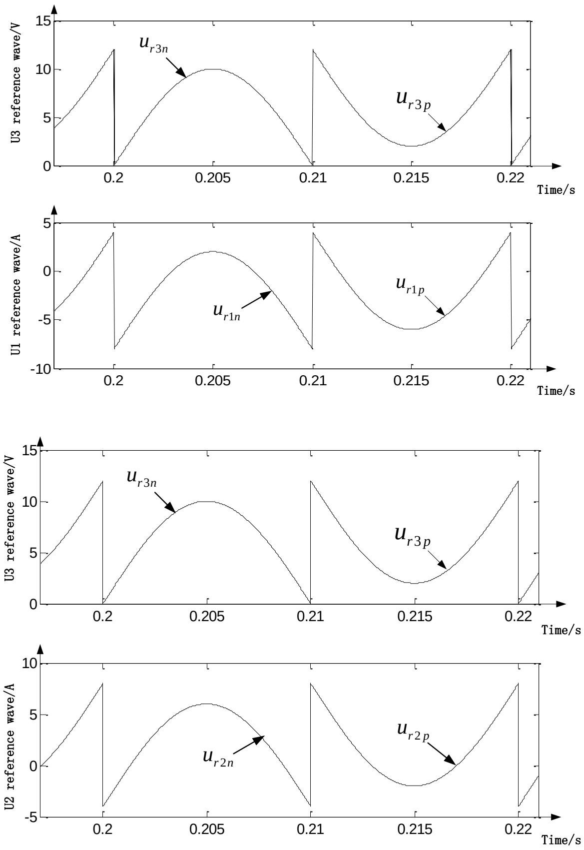

Fig. 7. Waveforms of three references of TRSPWM strategy

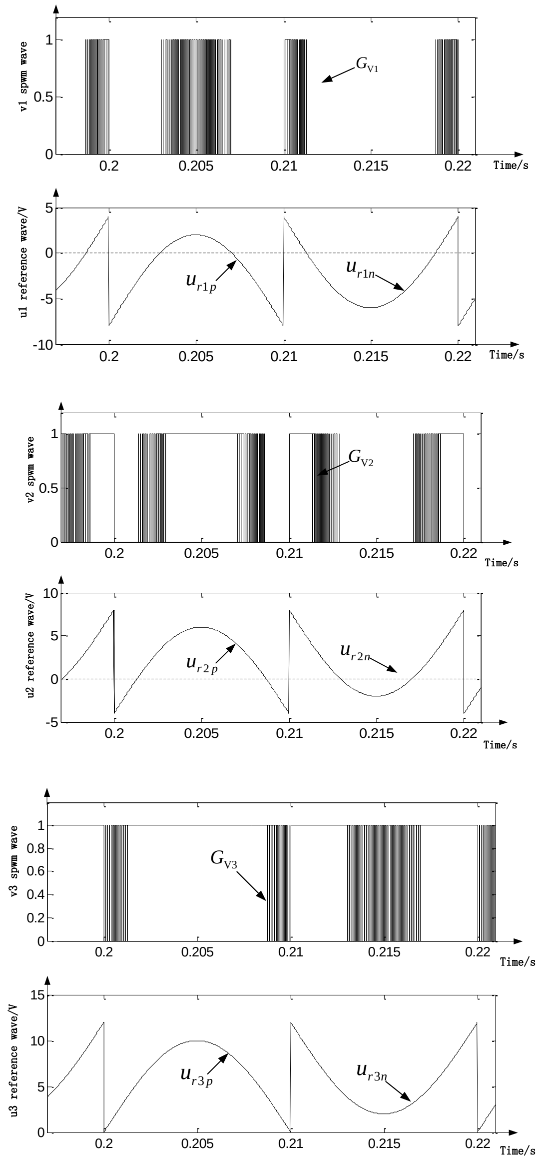

Fig. 8. The waveforms of driving signals for V1, V2, V3

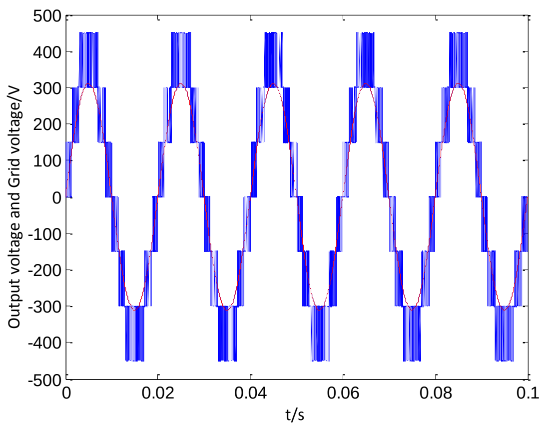

Fig. 9. The waveforms of seven level output voltage and grid voltage

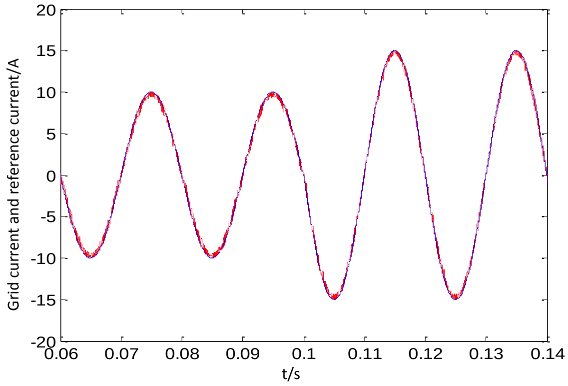

Fig.10. The waveforms of the grid current and the current reference

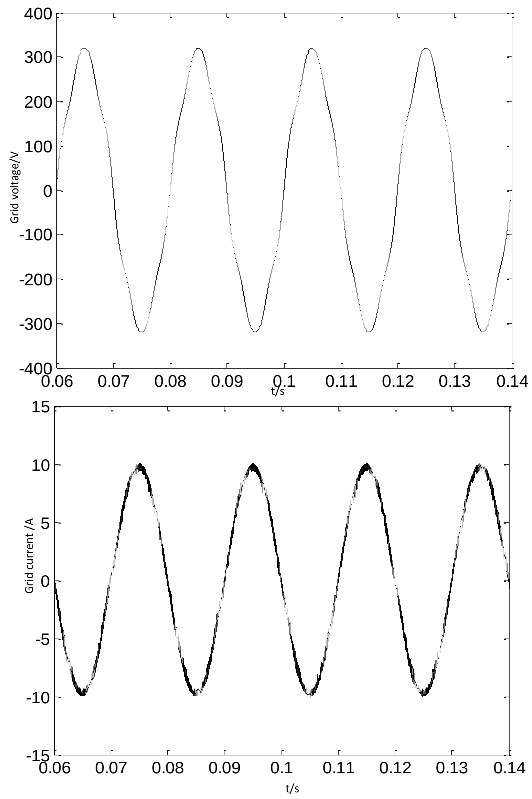

Fig.11 .Waveforms of grid current and the grid voltage with low order harmonic

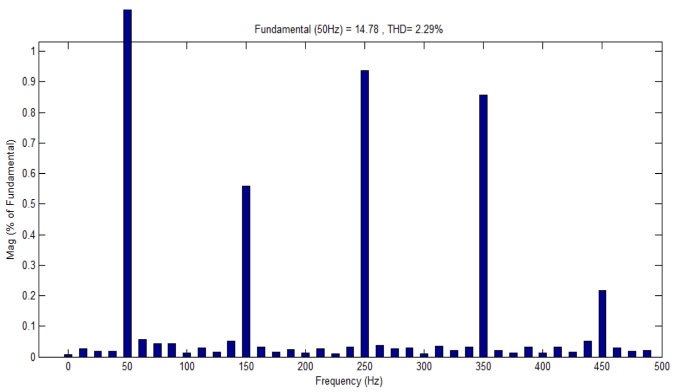

Fig.12 Grid current THD without a compensator

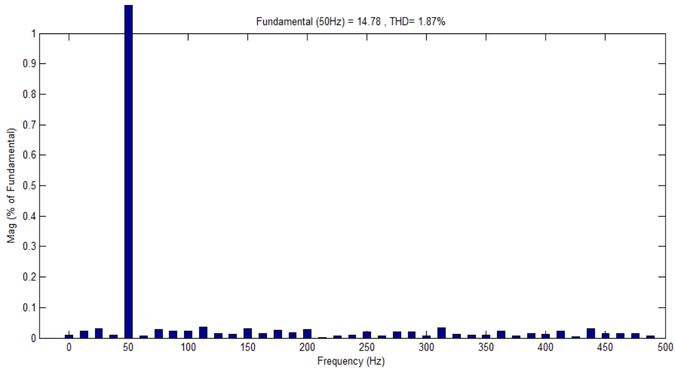

Fig.13 Grid current THD with a compensator

V. Conclusion

The seven level grid connected system based on the TRSPWM strategy and a Quasi PR current controller has a good output performance with a fast response and compensation for the low order harmonics in grid. The simulation based on MATLAB verify the proposed the accuracy and feasibility of the proposed scheme.

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