Abstract

To reduce the electromagnetic interference (EMI) of traditional PWM inverter, the paper puts forward a novel soft switching PWM inverter, expounds the inverter's configuration and working principle, analyses it's realization method, and validates it through simulation and experiment. The EMI conductive noise of AC inverter system was measured, analyzed and compared under hard switching and soft switching respectively. It testifies the validity of soft switching inverter on reducing EMI.

1. Introduction

In PWM inverter high frequency causes more output pulses during per period, so wave of the equivalent voltage much more closes to sine wave, which can reduce output harmonic wave and improve the speed governing performance. However, traditional inverter works under hard switching condition, namely the voltage and current mutate. The high switching frequency also cause switching loss, diode reverse recovery, inductive turn-off, capacitive turn-on and electromagnetic interference (EMI)[1-3], especially EMI. When working the inverter causes EMI to other devices, which gets severe with higher frequency. It involves mighty conductive EMI caused by high du/dt and di/dt of power devices, it also causes great electromagnetic radiation, which can cause mistake to itself and EMI to other equipments and affect their performance.

Soft switching involves zero voltage switching (ZVS) and zero current switching (ZCS). The switch turns on and off under ZVS or ZCS condition, which can restrict turn-on di/dt and turn-off du/dt, so as to reduce EMI.
2. The Novel Soft Switching Inverter

2.1. Topology soft switching inverter

The paper bring forward an novel parallel resonant DC link inverter (PRDCLI), its topology is shown in Figure 1. The system circuit includes auxiliary resonant link, inverter circuit and AC motor. The auxiliary circuit includes auxiliary switch T1, diode D1, auxiliary switch T2, diode D1, resonant inductance Lr and resonant capacitance Cr. The resonant inductance Lr and resonant capacitance Cr compose of resonant link circuit. The resonant link causes periodic ZVS grooves on DC generatrix, which provide soft switching condition for power devices S1~S6 of the 3-phase full bridge inverter. Compared with the prevenient similar circuits, the new topology’s advantage is all the switching devices operate under soft switching condition. Switch T1 turns on and off under ZVS condition, Switch T2 turns on under ZCS condition and turns off under ZVS condition. The main switches have no extra voltage and current stress. The circuit only has two extra auxiliary switches, so it is simple and easy to control. It can make voltage of DC generatrix descend to zero and hold for a needed time according to inverter PWM modulation and soft switching operation.

![Figure 1. Topology of novel PRDCLI](image)

2.2. Realization of soft switching

Realization of soft switching is to control auxiliary switches, its principle is shown in Figure 2. It utilizes TMS320LF2407 chip. By software setting, it can make EVA and EVB output wholly accordant PWM signals. But PWM signal of EVA delays behind that of EVB for a time Δt. Capture unit of TMS320LF2407 captures ascending edge of PWM signal of EVB, then the relevant interruption flag is set, and the peripheral interruption generates an interrupt request (IRQ). In the interrupt service subprogram, through software delay, it makes given pins of TMS320LF2407 output special control signals alternately. The signals make the auxiliary switch T1 and T2 turn on and off, which make the resonant link perform and make voltage of DC generatrix descend to zero and hold for a needed time. During the time the ascending edge of PWM signal of EVA comes and drives main switches of the inverter. The main switches of the inverter perform under ZVS condition. After main switch performance the auxiliary switches resonant link operate, which makes DC voltage recover to DC generatrix voltage. It is a whole resonant period, and waits for next operation.
Figure 2. Realization of soft switching

Simulation of control method

Shown in Figure 3 is simulation of matching between drive PWM signal of inverter main switch and resonance of the resonant link. Output PWM7 signal of DSP is the trigger signal, and output PWM1 signal of DSP is the drive signal of inverter. PWM7 signal advances PWM1 signal for 3.4 μs. In the figure, when ascending edge of PWM7 comes, the resonant link starts a period. When voltage of the resonant link descends to zero, the PWM1 signal comes and drives main switch of the inverter, and realizes ZVS. Then the resonant link keeps operating and makes DC voltage recover to DC generatrix voltage. It accomplishes a whole resonant period.

Figure 3. Simulation of matching between PWM and resonance

Experiment of control method

The experiment parameters: DC voltage: VD=200V, resonant inductance: L=1 μ H, resonant capacitance: C=3.8 μ F, resonant frequency: f=80kHz, switch frequency: f=10kHz.

Figure 4 shows the experimental drive signal of inverter main switch and resonant capture signal. The upper wave is the resonant capture PWM signal generated by EVB and the lower wave is the drive signal of inverter main switch generated by EVA. The two waves have a time discrepancy Δt, so as to make resonant auxiliary unit resonates ahead to generate ZVS condition for main switch.
Figure 4. Driver signal and resonant capture signal

Figure 5 shows the soft switching transition. When DC generatrix voltage resonates to zero, the PWM signal driving main switch of the inverter comes and realizes ZVS turn-on.

Figure 5. Soft switching waveform

Figure 6 shows experimental matching between DC resonant voltage and drive signal of main switch. When every drive signal of main switch comes DC voltage has resonate to zero, which creates ZVS condition for turn-on.

Figure 6. Matching of resonant groove and driver signal

3. Experimental Result and Analysis

3.1 Improving of turn-on peak of inverter switch

Figure 7 and 8 are voltage waves of main switches under hard switching and soft switching separately. Comparison between them can conclude that with resonant link the turn-on du/dt peak of main switch is improved greatly. The max turn-on du/dt peak of main switch decreases from 200V under hard switching to 140V under soft switching, the decreasing amplitude is beyond 30%. So it can reduce EMI greatly.
3.2 EMI EXPERIMENTAL result and analysis

Figure 9 shows total EMI(a), DM EMI(b) and CM EMI(c) of hard switching inverter.
Figure 9. EMI noise spectrum of hard switching inverter

Figure 10 shows total EMI(a), DM EMI(b) and CM EMI(c) of soft switching inverter.
Comparison between Figure 9 and Figure 10 shows that during the frequency range from 3MHz to 30MHz mostly the soft switching inverter greatly reduces EMI noise. The reason is that in soft switching inverter the main switches all turn on and off under ZVS condition, which reduces the switching du/dt and di/dt. Moreover the auxiliary switches T1 and T2 also operate under soft switching. The auxiliary switch T1 turns on and off under ZVS condition. The auxiliary switch T2 turns on under ZCS condition and turns off under ZVS condition.

Comparison of EMI noise frequency spectrum between hard switching inverter and soft switching inverter shows that soft switching inverter can greatly reduce conductive noise of traditional hard switching inverter, so as to reduce EMI to other equipments and ensure the system safe and normal performance.

References