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Phase Shift Control Based HVHFCPS With Steady Load Voltage

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Abstract— A high voltage capacitor charger finds its new applications in various pulsed power systems. In these applications, the pulsed power systems require high voltage power supplies that charge a load capacitor to a desired voltage .In this Paper a high voltage high-frequency charging power supply is designed in which charging rate is controlled accurately and also discharging characteristics of capacitor is studied.

Keywords— capacitorcharging powersupply,chargingrate, phase shift. 1,

I. Introduction

Typical applications of power electronics include power supplies, power conditioners, UPS systems, high voltage DC transmission systems, electronic ballasts, motor drives, and more recently, electric vehicles. A high voltage capacitor charger finds its new applications in various pulsed power systems. In these applications, the pulsed power systems require high voltage power supplies that charge a load capacitor to a desired voltage. With solid state semiconductor switches and high frequency switching technology, the physical size of a high voltage capacitor charger bas decreased dramatically and also, the cost has been reduced. Traditional methods of charging capacitors from a single phase supply include using a rectifier with a fly back converter .The disadvantage of these converters is the complexity of the control required to limit the current and voltage across the load capacitor. Conventional DC power supplies are normally designed for constant power applications and do not perform well under the wide range of load variations involved in repetitively charging a capacitive load from zero volts to a maximum voltage. A power supply specifically designed for capacitor charging applications that uses a series-resonant circuit topology**.** Resonant converters reduce the switching losses allowing the operation frequency of the converter to be raised. The main advantage of the capacitor charger are compact design, reduced switching loss, and more stable operation from the long wires between capacitor charger and load capacitor. Due to the simple structure of the series resonant circuit, the high voltage high-frequency charging power supply (HVHFCPS) is widely used. The disadvantage of such a power supply is that the charging rate cannot be controlled accurately, so it is only suitable for high-energy applications. In reference[2] HVHFCPS based on voltage feedback and phase shift control is presented where Charging Characteristics of Capacitor Charging Power Supply by setting different Set Voltages is analyzed where it is getting charged within in short time duration(10ms).Hence charging rate can be controlled accurately. In this Paper, Discharging characteristics of capacitor used in charging Power supply is studied where a bleeder Resistor is designed to discharge the Capacitor and is getting discharged within 10ms.Thus HVHFCPS finds it application in Pulsed Power System.

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2, CAPACITOR CHARGING POWER SUPPLY

Electrical equipment utilized in pulse power applications usually derives its bursts of energy by rapidly discharging a capacitor. Flash lamps, which may be used in sterilization or other applications that require flashes of high intensity light, and pulsed lasers, which may be used in cutting or welding, both derive the required bursts of energy in this fashion. The capacitors used in these types of equipment are energy-storage capacitors and must be charged by a capacitor-charging power supply (CCPS) prior to each repetition of energy release to the load. Fig.1 shows the voltage across the energy-storage capacitor connected to the output of the CCPS. As seen in this figure, the capacitor voltage is divided into two cycles; charge and discharge. During the discharge cycle, the CCPS is disabled while the capacitor is rapidly discharged by the load, which is inactive in the charge cycle. The discharge cycle is normally much shorter than the charge cycle. The CCPS enters the charge cycle with near short-circuit conditions across its output terminals and begins operation in the charging mode. In this mode, the CCPS operates at its maximum charging capability while charging the capacitor to the target voltage. The CCPS moves from the charging mode to the refresh mode when the target voltage is reached and remains in this mode until the load discharges the capacitor. The output voltage may drift due to capacitor leakage and parasitic resistances; the CCPS compensates for any drift by supplying a small current to the energy-storage capacitor.

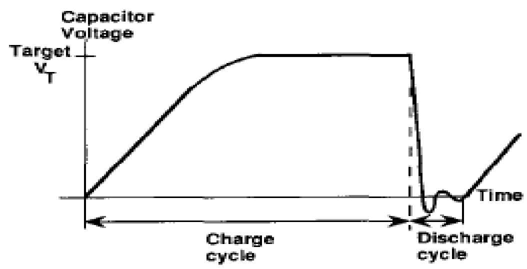

Fig 1.Capacitor Voltage

The average output power for a CCPS depends on the repetition rate and is a maximum when the capacitor is discharged at the end of the charging mode. In capacitor-charging applications, it is important to charge the load capacitor as rapidly as possible. The capacitor charge is directly related to the current flow through the resonant circuit and into the load capacitor. Two figures of merit that are useful in analyzing the capacitor-charging capability of the CCPS are its charging and average power output. The charging power is expressed in joules per second and is defined as the time rate of change of energy on the load capacitor during the charging mode

3, WORKING MODES OF CHARGING POWER SUPPLY

The resonant converter topology is widely used for high voltage capacitor charging applications due to its many advantages such as its current source characteristics and high frequency as well as its high-power operation with high efficiency [2]. To implement the high-performance capacitor chargers to the power cell-based SSPPM, three resonant converter topologies, namely, a series resonant converter operating at a discontinuous conduction mode with switching frequency control (SRC_DCM_SFC), a series resonant converter operating at a continuous conduction mode with phase shifted pulse width modulation control (SRC_CCM_PSPWMC), and a series–parallel resonant converter operating at the CCM with SFC (SPRC_CCM_SFC)

1)SPRC_CCM_SFC(**fs =>fr)**: The continuous current mode, which means the devices work in the hard switching mode in which the switching loss is large, and the electromagnetic interference is strong..

2**)** SRC_CCM_PSPWMC **(fr /2 < fs < fr)**: The continuous current mode. The devices work in the mode with hard switching on but soft switching off. In this mode, the switching loss is smaller and electromagnetic interference is weaker.

3) SRC_DCM_SFC **(fs < fr/2)**: The discontinuous current mode. The devices work in the soft switching mode. In this mode, the switching loss is the smallest and the electromagnetic interference is the weakest. This mode is appropriate for the low-power charging applications.

After comparing the three modes above comprehensively, the second mode is adopted in this paper.

3.1,**ANALYSIS AND INVESTIGATION OF SRC_CCM_ PSPWMC.**

Fig. 2 shows that the continuous sinusoidal resonant current waveform of the SRC_CCM exhibits a low conduction loss than the SRC_DCM. In addition, ZV turn-on can be realized by the resonance operation When the SRC_CCM-based capacitor charger operates under the SFC method, the switching loss will dramatically increase, particularly under a light load condition, switching frequency increases, and the resonant current value decreases with a decrease in the load On the other hand, the SRC CCM PSPWMC, which does not control the switching frequency but the delay between the leading and lagging leg switches, operates with a constant switching frequency In addition, the constant switching frequency operation of the SRC_CCM_PSPWMC makes filter design easy and controls the full-load range without audible noise.

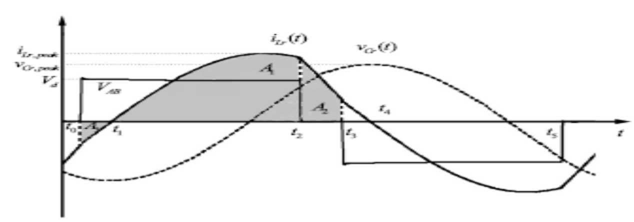

Fig2. Waveform of SRC_CCM_PSPWMC

3.2, WORKING PRINCIPLE OF HVHFCPS

The main circuit consists of a dc voltage source, full-bridge inverter, resonant circuit, high-frequency high-voltage transformer, high-voltage rectifier diodes, and the load. The control circuit includes the inverter’s control system, the protection system, and the optical fiber feedback system. The voltage signal is converted to a frequency signal by the optical fiber feedback system and then the frequency signal is processed by the inverter control systems, such as frequency to digital converting, proportional integral derivative regulation, phase regulation, pulse width calculation, and so on. The applicable driving pulses are sent to the devices of the inverter and the output voltage is controlled by the devices switching

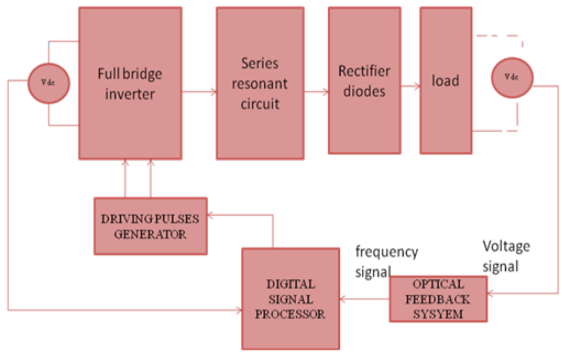

Fig 3.Block Diagram of Proposed System

The single phase full-bridge inverter consists of four gate controlled switches such as IGBT with freewheeling diodes. Fig 4 depicts the circuit diagram of HVHFCPS.All switches in the inverter operate with a duty cycle of 50%, ideally. The gate PWM signals of S2 and S3 are delayed with respect to those of the S1 and S4. The high voltage transformers are parallel connection at primary winding and series connection at secondary winding.

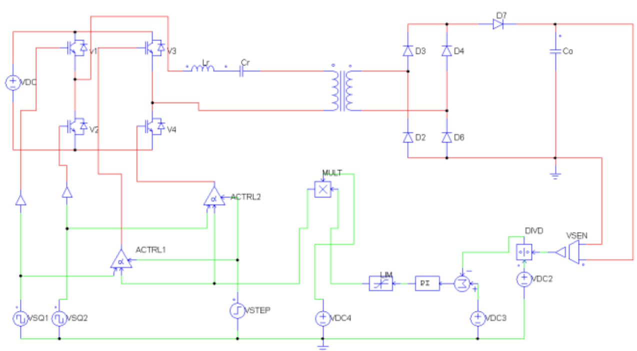

Fig 4.Circuit Diagram of Proposed System

3.3, PHASE-SHIFT CONTROL STRATEGY

Phase-shifted PWM control strategy has been used in order to achieve the driving pulses for four switches. The phase-shift Control is a mode in which the switch frequency is constant, but the phases of different bridges are variable. The output voltage can be controlled by regulating the phase difference The gate PWM signals of S2 and S3are delayed with respect to those of the S1 and S4.In the traditional series resonant circuit the switch devices V1 and V4 are defined as one group, and their drive pulses have the same phase. V2 and V3 are defined as another group, and their driving pulses are with 180° phase difference compared with V1 and V4[4].But in the phase shift control system, V1 and V2 constitute the ahead bridge, and their drive pulses are constant but opposite, V3 and V4 constitute the delay bridge, the driving pulse of V4 delays a phase to V1, and the driving pulse of V3 delays the same phase to V2. By regulating the phase difference, the devices switch state can be controlled. So that the output voltage can be regulated and the load voltage can be controlled. The relationship of the driving pulses and output voltage of the inverter at the situation that the delay phase between pulse of V4 and V1 is θ is shown in fig 5.

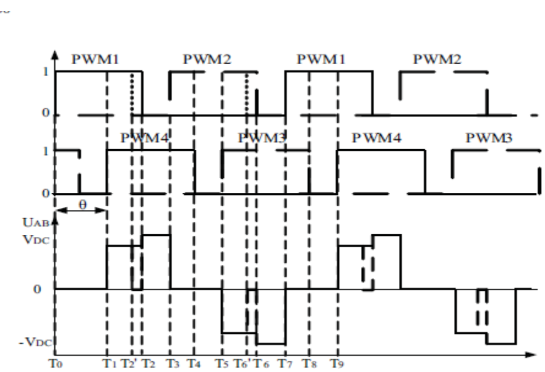

Fig 5. Drive pulses and inverter output voltage at different moments

Table I summarizes the inverter's output voltage, resonant circuit's current, and the switch devices work states of each moment in one switch period during the phase-shift process

Moment	**Work devices**	**Inverter Voltage**	**Resonant current Direction**
	V1+V4	+Vdc	+
	D2+V4	0	+
	D1+V4	+Vdc+Vd1	_
	V2+V4	0	_
	V2+D4	0	_
	V2+V3	-Vdc	_
	D1+V3	0	_
	D2+V3	-Vdc-Vd1	+
	V1+V3	0	+
	V1+D3	0	+

4, DESIGN OF CIRCUIT PARAMETERS (10 KV)

Specifications

Let =540V, =5µH, =37.1kHZ, =10kv, =10msec, fs= 21.7 kHz

Where

= input voltage = maximum charging voltage, =load capacitance, =charging time, =resonant frequency

n= =19 (1)

Where n=transformer ratio

C = = 1.21 µF (2)

Where C=compound resonant capacitance

= =9680mF (3)

= =1.21µF (4)

Where =resonant capacitance

Lr = = 15.5µH (5)

Where Lr= resonant inductance

5, Design of circuit parameters (4kv)

Specifications

Let =540V, =5.6µH, =37.1kHZ, =4kv, =10msec, = 21.7 kHz

Where = input voltage, = maximum charging voltage, =load capacitance, =charging time, =switching frequency, =resonant frequency

n= = 8 (6)

Where n =transformer ratio .The resonant inductance of 15 mH is the stray inductance of the high voltage transformer. The capacitance of the resonant capacitor can be calculated by

C = (7)

=

= 1.2µF

6, SIMULATION RESULTS

In order to prove the phase-shift control strategy based on voltage, feedback signals can be applied in HVHFCPS, a simulation system based on phase-shift control that was constructed on the PSIM platform

6.1,PI CONTROLLER

PI controller will act to lead steady state control error to zero. It can be concluded that PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. When the phase-shift angle is put into the phase-shift converter, the output will generate the driving pulse with a changed phase then the phase-shift control of the inverter can be realized. The system is the voltage feedback control system, so the rising time of the output voltage can be regulated by changing the preset value and the parameters of the PI regulator.The charging voltage of the load can be controlled accurately at the value of 10 000 V, and the charging time is less than 10 ms. (Fig 7). If we change the setting value of the charging voltage, which is marked as V-setting, the charging voltage ,can be controlled to reach to the setting value. And if we change the parameters of the PI modulator, the charging rate can be controlled accurately.

In the simulation system, a dc voltage source is adopted as the input source and the value is 540 V. The driving pulses are generated by a square-wave generator and the frequency of the pulse is 21.7 kHz, so the inverter's work frequency fs is 21.7 kHz. According to the relationship of fr, Cr, and Lr, the fr is set to 37 kHz, the Lr is set to 15 µH, and the *Cr* is set to 1.2 µF. The ratio of the transformer is set to 1:19, so the output voltage of the transformer can reach more than 10 kV. The load of the simulation system is a capacitor whose value is 5 µF, so a waveform of the whole charging progress can be obtained in a short time

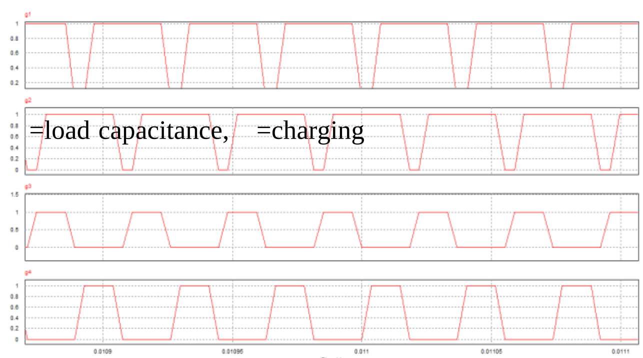

Fig 6.PWM Pulses for the switches

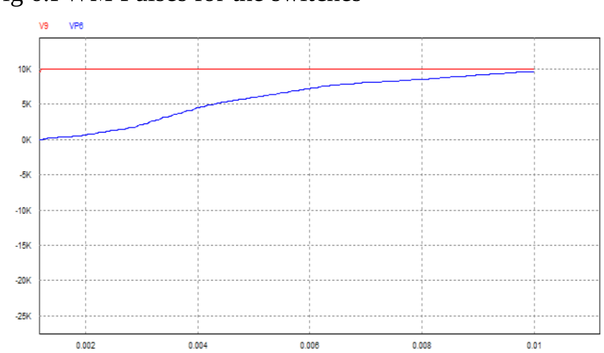

Fig 7.Simulation result of the load voltage when V-setting is 10,000V

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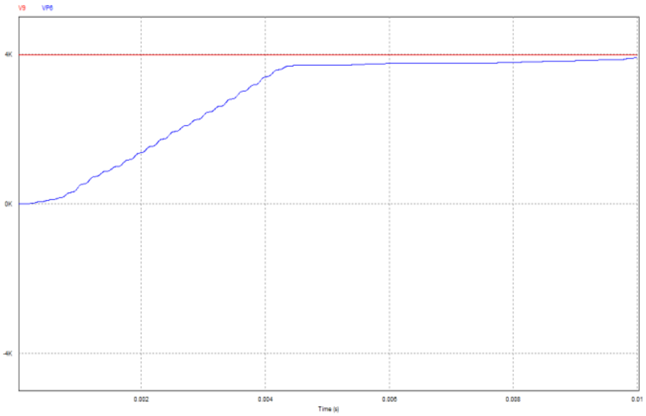

Fig 8.Simulation result of the load voltage when V-setting is 4000V

6.2, CAPACITOR DISCHARGING

A capacitor is a passive device that stores energy in its electric field and returns energy to the circuit whenever required. When the capacitor is fully charged, discharging can be done with the help of resistor. Here the load capacitor which is charged to 10,000v in 10ms has to be discharged. Switch S1 is closed and Switch S2 is kept open by giving appropriate gating Pulses, during this time capacitor is charged to the load voltage .Similarly S1 is open and Switch S2 is kept closed and capacitor discharges through the resistor which is shown in fig 11.Bleed resistors are used to discharge capacitors to safe voltage levels after power is removed (Figure 9).A bleeder resistor is a resistor placed in parallel with a high-voltage supply for the purposes of discharging the electric charge stored in the power source's filter capacitors or other components when the equipment is turned off, for safety reasons. A bleeder resistor is usually a standard resistor rather than a specialized component

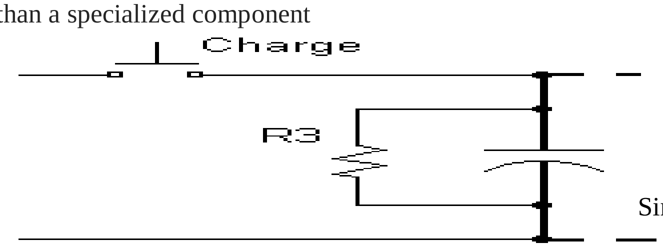

Fig 9. Switched Bleeder Resistor

Selecting a maximum suitable ohmic value is achieved from an exponential discharge calculation (Figure 10)

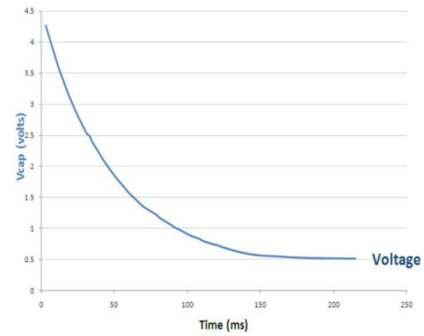

Fig 10. Discharging Characteristics of capacitor

= =

( )

= =860Ω (8)

Where Td is discharge time, C is capacitance value assuming maximum positive tolerance, Vt is safety threshold voltage and Vo is the initial voltage. The closest standard value below Rmax should be used.

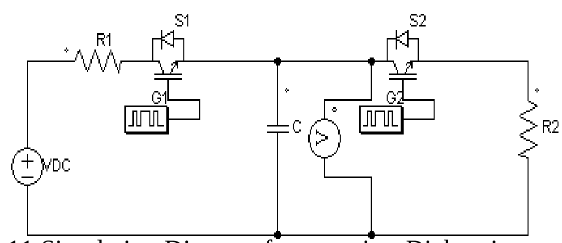

Fig 11.Simulation Diagram for capacitor Dicharging

The capacitor is discharged and the corresponding Simulation result is shown in fig 12

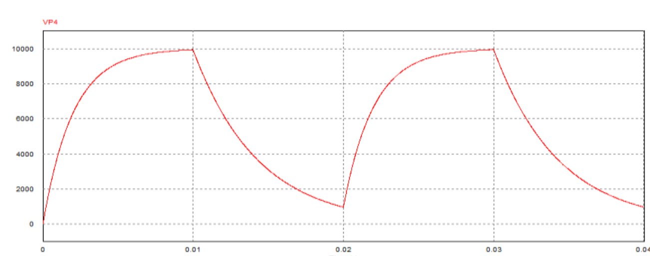

Fig 12.Simulation Result of Capacitor Discharging Circuit

7, CONCLUSION

In this Paper the power supply based on the phase-shifted control was designed. The control strategy was proven to be effective by the PSIM simulation results. The charging voltage of the load is controlled accurately at the value of 10 000 V and 4000 V, and the charging time is less than 10 ms. The charged Voltage was discharged in another 10 ms. If we change the setting value of the charging voltage, the charging voltage , can be controlled to reach to the setting value. And if we change the parameters of the PI modulator, the charging rate can be controlled accurately.. The load's voltage was sampled through the optical fiber and converted to a digital signal which was processed in the digital signal processer. The output voltage was controlled by changing the phase-shift angle which was obtained from the processed signal.

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