SIMULATION A HIGH STEP-UP DC-DC CONVERTER FOR ACCELERATOR

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Abstract

This paper simulation a novel high step-up DC-DC high circuit architecture for storage ring quadrupole and sextupole power supply DC bus voltage. The input source is a low voltage photovoltaic energy through proposed circuit to increase high output voltage system. This voltage can be as DC bus of quadrupole and sextupole power supply. The part of the circuit has a power switch, isolated transformer inductors, switched capacitors and diodes. This proposed circuit has the advantages of galvanic isolation function, small transformer and high step-up gain and efficiency. Continuous conduction mode (CCM) operation principles are discussed in this paper. Finally, Simplis software has been used for simulation a 24 V_{dc} step-up to 200 V_{dc} and 100 w DC-DC converters.

Keyword: high step-up, switched capacitor, photovoltaic

INTRODUCTION

Taiwan Photon Source (TPS) was established in 2010 and laboratory equipment to be completed in 2014. Taiwan photon source accelerator perimeter is 518m and energy of 3GeV. Storage ring quadrupole power supply 240 units, sextupole power supply 168 units. It is resolution with high precision and high stability. However, as the energy crisis and ecological protection issue being taken seriously, renewable energy is becoming increasingly popular used in accelerator power. Many scholars study the use of renewable energy as a power supply input voltage source, while the photovoltaic system generates surplus energy to the load power consumption, the recovered energy to the power companies. The conventional boost converters due to duty ratio limit are not achieve high step-up ratio and cause a high voltage stress on switches devices and high conduction loss lead to reduced power circuit efficiency [1]. While coupled inductor technology can achieve high step-up ratio function, but will have a leakage inductor cause surge spike voltage when the switch is turned off, the surge spike voltage can be suppressed using a buffer circuit, but it will result in reduced efficiency of the power circuit [2]-[4].

From the above discussion, this paper proposes the use of boost architecture and a set of isolated transformer integrated switched capacitor technology. Switched capacitor can store energy when switch device is turned on and energy source for photovoltaic energy. When the switch device is turned off, the energy delivered to the output loading. The proposed circuit is composed of a main switch S, an isolation transformer T, switched capacitor C_s, two diodes (D_1 & D_2) and a large output capacitor C_o. Isolation transformer turns ratio is N_p:N_s = 1: 4, the magnetizing inductance L_m is 100uH. The proposed circuit advantages: high efficiency, small size, high step-up ratio and cost down. Proposed circuit diagram and component parameters will be discussed in Section II. Section III will analyze the continuous conduction mode of proposed circuit. The simulation results will be presented in the Section IV. Finally, conclusion is presented in Section V.

PROPOSED CIRCUIT DIAGRAM

The proposed circuit equivalent circuit is shown in figure 1. Proposed circuit element comprising: an input source is photovoltaic system, an isolated transformer N_p:N_s is primary winding and secondary winding, L_m is magnetizing inductance. Stress voltage and current of L_m is named as V_{L1} and i_{Lm}. NMOSFET is high frequency main switch, capacitor voltage of main switch is given by V_{ds} and current of main switch is given by $i_{ds.}$ Secondary side have a switch capacitor (C_1), secondary winding (N_s) and freewheel diode (D_1), stress of switch capacitor (V_{c1}) is stored energy at main switch is turned on. Else, switch capacitor is released energy to output loading at switch is turned off. Stress voltage and current of secondary winding are given by V_{L2} and i_s. N_p:N_s is equal to 1:4. Output current and voltage is V_o and i_o. a large output capacitor parallel with output resistor to reduce voltage ripple at output loading, the current and voltage of large capacitor are named as i_{co1} and V_{co1}. Figure 2 has shown key component current and voltage waveforms. Table 1 has shown key component parameter in the simulation study for a proposed circuit. Continuous conduction modes operations are discussed at section III.

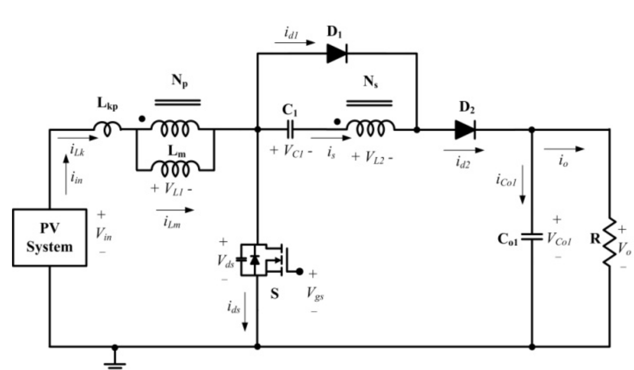

Figure 1: Proposed circuit equivalent.

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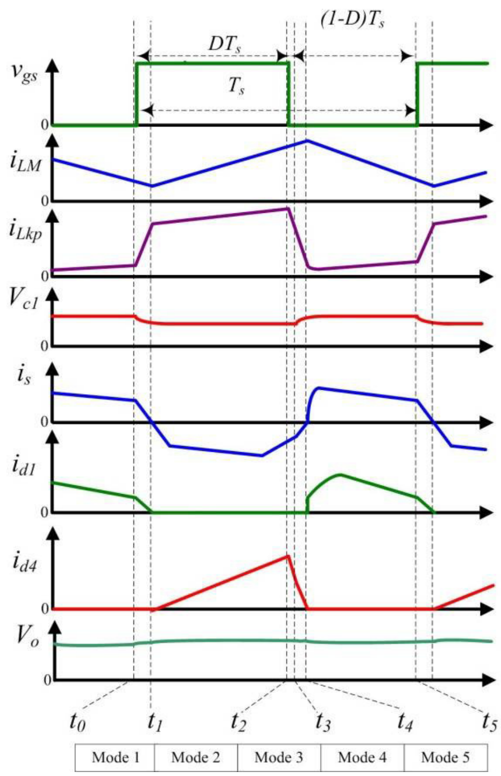

Figure 2: Key component current and voltage waveforms.

Table 1: Key component parameters in the simulation

No	Parameters	Specification
1	DC Input Voltage	24 V
2	DC Output Voltage	200 V
3	Output Power (max)	100 W
4	Switch Frequency	50k Hz
5	Output Current (max)	0.5A
6	Turn ratio (N_p:N_s)	1:4
7	Magnetizing inductor (L_m)	100u H
8	Leakage inductor (L_k)	1u H
9	MOSFET (S)	Ideal
10	Diodes (D_1 & D_2)	1N4148
11	Capacitor C_1	20u F
12	Output Capacitor C_{o1}	470u F
13	Output Resistor	400 omh
14	Output voltage ripple	0.2 V

CONTINUOUS CONDUCTION MODE OPERATION

The proposed circuit continuous conduction mode has five operating modes in a period by switch duty cycle.

Mode I [t_0, t_1]: Power switch is turned on, D_1 is forward bias and D_2 is reverse bias. Magnetizing inductor charge energy by photovoltaic system that magnetizing inductor current i_{Lm} linearly increases. Secondary winding is charged energy by capacitor (C_1) via diode (D_1) and inductor energy by primary winding.

Mode II [t_1, t_2]: Main power switch is turned on, magnetizing inductor and capacitor (C_1) charge energy by photovoltaic system and secondary winding via diode (D_2). Magnetizing current i_{Lm} and secondary winding current i_s are linearly increase until main power switch is turned off at t_2. Stress voltage and current of primary and secondary wingding at mode II. The equations are given by:

$$V_{L1}{}^{II} = V_{in} \tag{1}$$

$$V_{L2}{}^{II} = nV_{L1}{}^{II} = nV_{in} \tag{2}$$

$$i_{Lk}{}^{II}(t) = V_{in}^{II}(t) - V_{in}^{I}(t)/L_m + L_{kp} \tag{3}$$

According mode II, capacitor C_1 release energy to secondary winding, across voltage of V_{c2} can be written:

$$V_{c1} = nV_{L1}{}^{II} = nV_{in} \tag{4}$$

Mode III [t_2, t_3]: At this time, power switch is turned off, capacitor of switch charge energy by photovoltaic system and magnetizing inductor, magnetizing current i_{Lm} is started to decrease. Capacitor (C_1) is charged energy and secondary winding is released energy via diode (D_2). This operation mode end when Stress voltage of switch is full charging $V_{ds(max)}$. Stress voltage of switch is given by

$$V_{ds}(t) = V_{in} + V_{L1}(t) \tag{5}$$

Mode IV [t_3, t_4]: At this time, parasitic diode of main switch is turned on, capacitor (C_1) charge energy by secondary winding via diode (D_2). This operation mode end when secondary winding current (i_s) decrease to zero.

Mode V [t_4, t_5]: Main power switch is turned off, diode (D_2) is reverse bias and diode (D_1) is forward bias. Capacitor (C_1) releases energy to secondary winding via diode (D_1). This mode operation will be ended at t_5 when power switch is turned on to the next period.

SIMULATION RESULT

This proposed circuit converter is simulated use by Simplis software. Switch frequency is 50k Hz and input voltage is 24 V_{dc} step-up to 200 V_{dc}. NMOSFet is used an ideal power switch to simulation for simply discuss, pulse width modulation (PWM) voltage is 15V_{pulse} and 50k Hz, parameter of component is shown in table 1. The simulation results of isolated transformer primary and secondary winding measurement current are shown in Figure 3. Green curve is pulse width modulation voltage (V_{gs}) versus brown curve is primary winding current of isolation transformer and yellow curve is secondary winding current of isolated transformer. Main switch is turned on when pulse width modulation voltage is high level, primary winding current linearly increase current from 0A to $i_{Lk(max)}$ =10.2A and secondary winding current linearly decrease from 0A to -0.6A. Else, primary current is linearly decrease and secondary current form 1.6A decrease to 1.25A. Figure 4 is shown V_{gs} versus current of D_1 (i_{d1}) and current of D_2 (i_{d2}). Main power switch gate to source voltage (V_{gs}) is high level, D_1 is forward bias and D_2 is reverse bias. Secondary winding is charged energy by capacitor (C_1) via diode (D_1) and inductor energy by primary winding, i_{d1} current is linearly increase and i_{d2} current is zero. Else, main switch is turned off, capacitor (C_1) charge energy by secondary winding via diode (D_2) and D_1 is reverse bias. Figure 5 is shown simulation voltage of capacitor 1 (C_1) and output voltage.

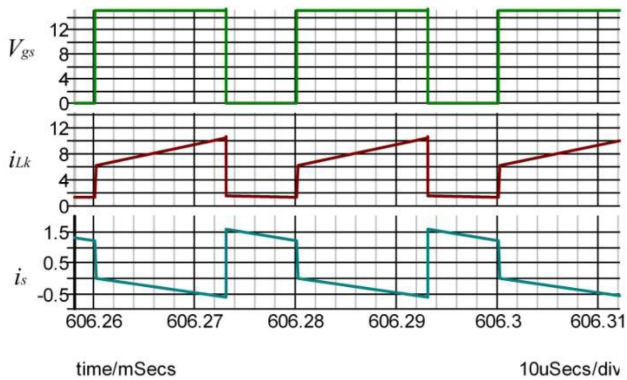

Figure 3: Simulated waveform of v_{gs}, i_{LK} and i_s.

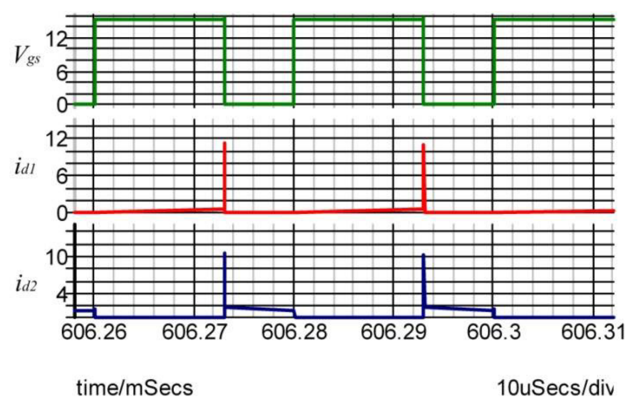

Figure 4: Simulated waveform of v_{gs}, i_{d1} and i_{d2}.

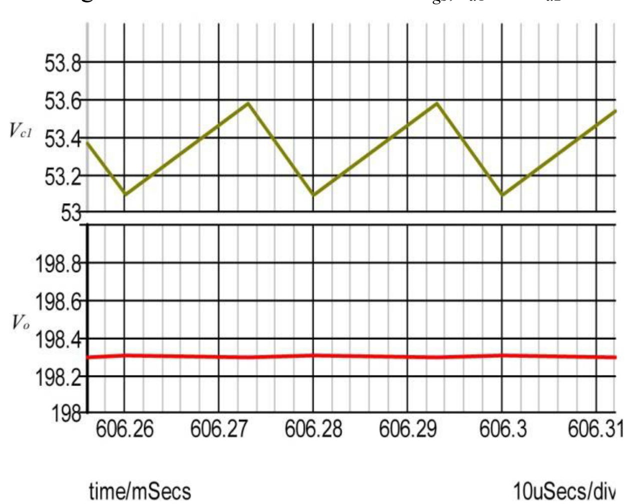

Figure 5: Simulated waveform of v_{c1} and v_o.

CONCLUSION

For this paper, a novel high step-up DC-DC converter for storage ring magnet power supply had been simulated. Using an isolated transformer and switch capacitor circuit to achieved high voltage gain. Through this proposed circuit architecture, the low voltage of PV system can be produced to a high output voltage, in order to provide energy to the DC bus of quadrupole and sextupole power supply. Simply circuit and fewer components to get a high voltage gain, stress voltage of switch capacitor and main switch will be reduced. Therefore, low conduction resistance and low voltage stress component can be selected to improved power converter efficiency. Finally, an input voltage 24-V_{dc}, output voltage 200-V_{dc}, and output power 100-W had been simulation to proof performer for this proposed circuit.

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