論 文
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500MW 화력 발전소 전기 집진기용 고압 펄스 전원 장치 개발

Development of a High Voltage Pulsed Power System for Electrostatic Precipitators

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Abstract - With the increasing demands for clean environment, development of air cleaning systems has been received increasing attention. One of the key technologies in the electrostatic precipitator (EP) is high voltage pulsed power supply, which affects the performance of the overall system.

In this study, a high voltage microsecond pulse power supply for the EP is developed for 500MW coal power plants.

The power supply has a dc source and a pulsed one. The ratings of the dc and the pulse source are 60kV, 800mA and 70kV, 400mA, respectively. The width of pulse voltage is 140us and the max. pulse repetition frequency is 200Hz.

Key Words : Electrostatic Precipitator, Pulse power, Coal Power Plant

1. Introduction

The trend of the regulations on environmental issues are getting tight. Responding to the movement new technologies such as moving electrodes, wide pitch and pulsed power supply are also introduced in the electrostatic precipitator systems. The introduction of wide pitch and moving electrodes enhances the system performance of the EPs by improving air-flow and by improving the ash re-entrainment on rapping, respectively.

The power supplies for the EPs developed up to date include thyristor-based dc or intermittent type, SMPS(switching mode power supply) type[1] and the pulsed-power supply type[2-3]. The use of the pulsed ones is known to improve dust-collecting efficiency of high resistivity ash and minimize back corona occurrence in the collecting plate. There are many kinds of pulsed-power supplies[4-6] for EPs and direct dc switching types are widely used. Rotary spark gap switches or semiconductor switches are used in direct dc switching type power supply. Both have the merits and demerits: the spark gap switches are simple and robust but has short life time, hence, high maintenance cost, whereas the semiconductor switches have long life time but are costly.

In this study, a high voltage microsecond pulse power supply for the EP is developed for 500MW coal power plants. This study describes circuit topology, operating modes of the scheme, construction of high voltage switch using fast thyristors, and analyzes experimental results.

The power supply has a dc source and a pulsed one. The dc base voltage applied to the EP is supplied by a separate variable dc power supply and the pulse voltage is generated by switch string, a resonant inductor and capacitor and the inverter. The ratings of the dc and the pulse source are 60kV, 800mA and 70kV, 400mA, respectively. The maximum pulse repetition is 200pps(pulse per second) and the pulse width is 140us.

2. Description of the scheme

A. Conventional dc power supply

The dc or intermittent power supply is shown in Fig.1. It is made of an anti-parallel connected thyristor pair, a

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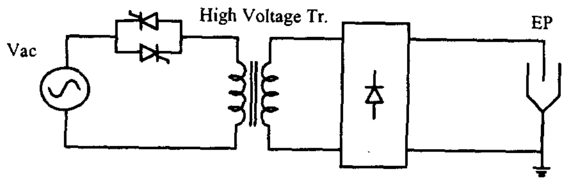
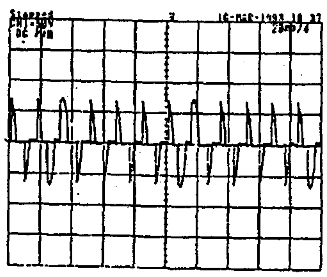
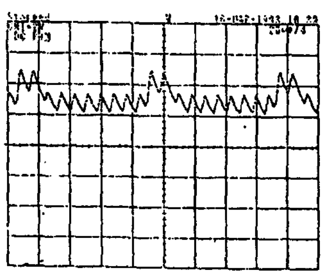


Fig.1. High voltage dc power supply

high voltage transformer and a high voltage diode rectifier. It is a kind of a high voltage rectifier that has voltage-regulating capability. But the use of a digital controller enables the intermittent voltage and pulse regulations on the output and, hence, minimizing energy consumption without deteriorating the system performance. The waveforms of the input current and the rectified output voltage are shown in Fig2.(a) and (b), respectively.



(a) Input current(20mA/div)



(b) Output voltage(20kV/div)

Fig. 2. Experimental waveforms of the high voltage dc power supply

Two high voltage-pulses are observed every 10 pulses. The magnitude and the number of higher voltage pulses can be controlled. However, the pulse repetition rate is fixed as two times of the source frequency. The continuous voltage shown in Fig.2(b) shows capacitive characteristics of the EP reactor between the discharging and collecting electrodes. A typical construction of the EP reactor is depicted in Fig.3.

B. The proposed pulsed-voltage power supply

Fig.4 shows the proposed pulsed-voltage power supply. The scheme consists of a thyristor-based variable dc power supply with voltage rating of 60kV and a pulse generator which is made of an inverter operating with 5kV dc source, a high-voltage semiconductor switch string(TD), an LC resonant tank(Ls,Cs) and a blocking inductor(Lb).

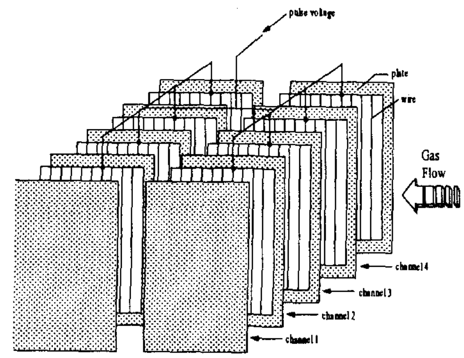


Fig. 3. Discharging wire electrodes and collecting plate electrodes

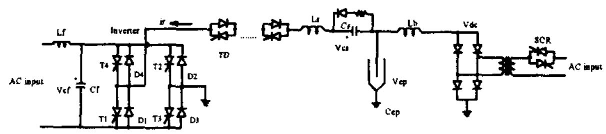


Fig. 4. Proposed scheme

The output voltage applied to an EP is a negative voltage pulses and a rectified dc voltage with negative polarity resulting in producing negative corona between the discharging electrodes and the collecting plates. The output has pulsed voltage trains that are superimposed on the dc base voltage. The output pulse voltage has pulse width and peak voltage of 140us and 70kV, respectively. The pulse repetition-rate is variable up to 200pps.

The dc source on the right hand side with respect to the EP provides dc base voltage. The base voltage can be controlled by the thyristors in the single-phase ac source. The pulsed voltage source on the left hand side generates variable pulse-voltage up to 70kV using a 5kV dc and a thyristor-based inverter, a high voltage switch(TD) and a resonant tank mode of Ls and Cs. The inductor, Lb, prevents pulse-current flowing into dc source from the pulse source.

C. Pulse voltage generation

Fig.5 illustrates pulse forming of the proposed scheme in the steady state. Before the pulse being generated, the capacitor, Cs is charged to a voltage of V_{Cs}. A series resonant circuit is built by the storage capacitor Cs, the EP capacitor C_{EP} and the inductance Ls when the high voltage switch TD is closed.

Depending on the switching status of the inverter, 5kV dc can be involved in the resonant circuit:

- With turning on T1 and T2 [in Fig.4 and Fig.5]

T1, T2 and TD are forward biased and Vcf is added to Vcs. At time of t1 the direction of the current i_r is reversed and diodes in TD are forward biased.

- With turning on T3 and T4 [in Fig.4 and Fig.5]

T3 and T4 are forward biased, hence, Vcf is added to V_{EP}. When the current i_r through the diodes of TD becomes zero, the resonant oscillation is over and one voltage pulse has been generated.

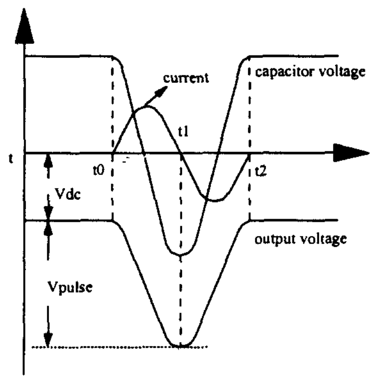


Fig. 5. Pulse forming of the proposed scheme

The pulse repetition rate can be varied up to 200pps by controlling this pulse time-interval. The inverter is used to build up the pulse voltage as required and compensates the losses in the circuit and in the EP.

The dc link voltage in the inverter can be controlled by three phases thyrister rectifier in the front end.

D. Switch construction

Fig.6 shows a thyristor-diode unit with driving circuit. A break over diode(BOD) is connected across the unit to protect the switch against voltage spikes. The LED display each switch module condition.

A string of 100 fast thyristors and anti-parallel diodes in series constitute the high voltage switch. Every four thyristor-diode devices are built on a printed circuit boards(PCB) and form a switch module. Each module has one iron core for triggering pulses.

Two versions of the switch module are shown in Fig.7. The first prototype is shown on the right hand side. It is made of one pulse-transformer core with one switch set (230*140*40=1,288x103mm^3) where as the other one (280*200*40=2,240x103mm^3) has only one pulse-transformer core with four secondary wires to drive four switches. Hence, it minimizes the cost, switch space and weight.

Fig.8 illustrates the complete switch configuration with driving circuits. Each thyristor is triggered by a gate pulse generated by a triggering circuit(Vpulse). The triggering signals are generated from dc 1kV to drive the 100 thyristors with pulse width of 20us. Compared to one-switch one-trigger circuit scheme, this driving system minimizes the jitter of the thyristor switches. The size of iron core is determined by the required isolation in the transformer oil. The inner and outer core diameters used in this study are 60mm, 84mm, respectively, with iron thickness of 0.3t. As a provision of insulation and cooling, the complete switch mounted on PCBs is immersed in the transformer oil.

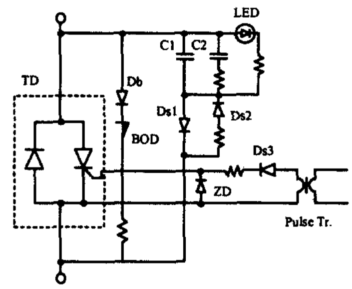


Fig. 6. Thyristor-diode unit with driving circuit

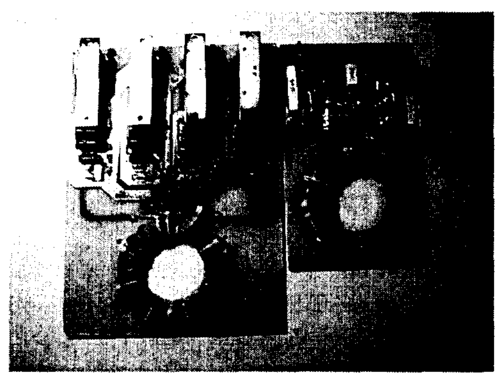


Fig. 7. Switch modules

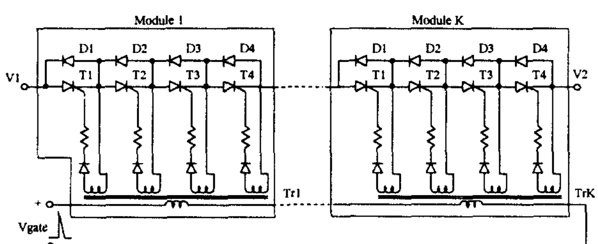


Fig. 8. Complete switch configuration

3. Experimental results

The waveforms of the voltage across the EP and the current through the switch are shown in Fig.9. The output voltage shows pulses superimposed on dc base voltage. The current has a sinusoidal waveform. It flows through the thyristors during the positive half cycle, whereas during the negative half cycle it flows through the diodes. The magnitude of the negative half-cycle is much smaller than that of the other due to the corona power dissipation in the EP. During the negative half-cycle the energy that is not dissipated in the EP is recovered through the diodes, hence, high system efficiency is obtained.

Fig.10 shows the output current with thyristor triggering signals. The leading edge of the signals determines the switching-on time of the thyristors. The additional signal at the point of zero current crossing provides bi-directional current path for the spark over inside the EPs.

If the sparks occur, the load(EP) is short-circuited and surge current starts to flow through the thyristors. Once this happens, the energy in the EP and in the resonant circuit (Cs and Ls) is to be dissipated in the dump resistor across the Cs which is shown in Fig.4.

The waveform of the voltage across one of the high voltage switch is shown in Fig.11. The voltage across the high voltage switch is zero during the turn on time(140us) but the waveform shows a oscillation when the switch is turned off. This is caused by the stray components in the switch circuit.

Fig.12 shows the output voltage waveforms for EP at 100pps. The output voltage shows 45kV pulses superimposed on 13kV dc base voltage. These waveforms were measured directly on the EP.

Fig.13 shows the soft starting right after the spark occurs. Delay time Td is required for the system to exclude reoccurring of the spark over. The output voltage increases gradually during Tb and reaches the pre-set voltage.

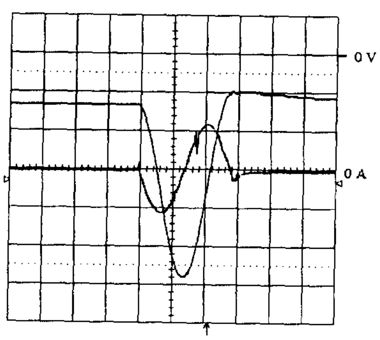


Fig. 9. The voltage across the EP and the current through the switch(50us/div, 10kV/div, 50A/div)

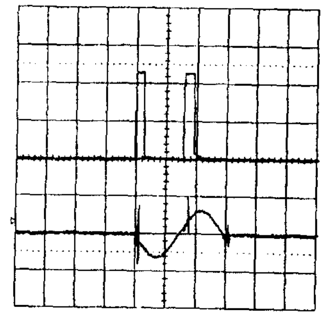


Fig. 10. The output current with thyristor triggering signals(50us/div, 5V/div, 50A/div)

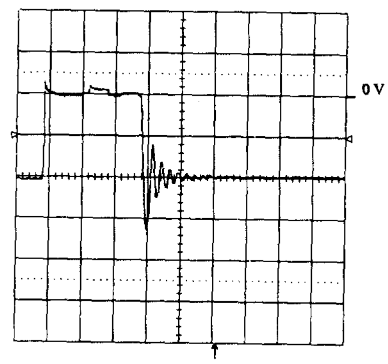


Fig. 11. The waveforms of the voltage across one of the high voltage switch(50us/div, 500V/div)

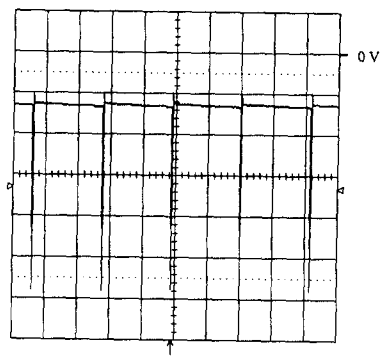


Fig. 12. The waveforms of the voltage across the EP at 100 pps(5ms/div, 10kV/div)

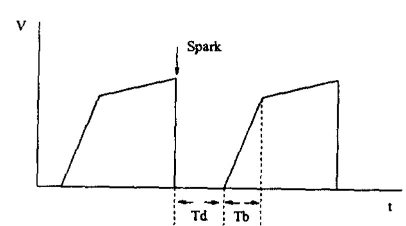


Fig. 13. The soft starting right after the spark occur

4. Conclusions

The microsecond pulsed-power supply with a very high voltage semiconductor switch is proposed in this paper. The power supply has a dc source and a pulsed one. The ratings of the dc and the pulse source are 60kV, 800mA and 70kV, 400mA, respectively. The width of pulse voltage is 140us and the max. pulse repetition frequency is 200Hz.

A very high voltage semiconductor switch using fast thyristor-diode modules are designed, built and verified through this study. The switch is built on PCB boards in the modular form and is driven by pulse transformers that are immersed in the transformer oil for cooling and isolation. Using the inverter circuit for pulse generation this scheme needs small isolation space. So, this scheme reduces size and cost of total system.

Key performance characteristics are also experimentally verified with a prototype.

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APPENDIX

The followings are component ratings and values used in the scheme.

A. Main circuit
- TD : ABB TD46F12(1200V, 46A)
  20us of turn off time
- Ls : 7.4mH
- Lb(Blocking inductor) : 33H
- Cs : 200nF(200kV)
- Cf : 40uF(5kV)

B. Gate driver
- TD : ABB TD46F12(1200V, 46A)
  20us of turn off time
- BOD : ABB BOD 1-09A(900V)
- Db : Fr607(1000V, 6A)
- Ds1, Ds2, Ds3 : Fr107(1000V, 1A)
- ZD(zener diode) : 1W 15V
- C1(Snubber cap.) : 0.015uF(1600V)
- C2 (Snubber cap.) : 0.1uF(1600V)
- Core type : Laminated iron core

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