Research on High Frequency Switched HV Power Supplies for ESP

WANG Renjin[1], WEI Yunfeng[2]

(1 Zhejiang Jiahuan Electronic Co., Ltd, 188 Jiangjun Road, Jinhua, Zhejiang 321000, PR China
2 Genvolt, New Road, Highley, Bridgenorth, Shropshire, UK)

Abstract: High voltage switching power supplies have found wide applications in many fields, and great progress in ESP also has been made in recent years. In this paper many concepts on designing a high frequency switched HV power supply have been presented, the paper also briefly describes a newly developed 32 kW high frequency switched HV power supply for ESP.

Keywords: series resonance, voltage multiplying

1 INTRODUCTION

People have become to realize the significant advantages of high frequency switched HV power supply in ESP in recent years. Many researching reports also show it could greatly improve dust removal efficiency and enhance power factor. When working at intermittent mode, problems arising from back corona could be handled more easily and collection of fly ash with high resistance also improved because the turning-off and switching-on duration have been shortened dramatically.

Unlike other applications, high frequency switched HV power supplies have to work in extremely strict environment due to ESP working condition and its loading characteristics. Firstly, the power supply must be placed on the roof of a house, there will be many factors such as temperature, moisture, altitude and dust loading should be taken into considerations when designing it. Temperature alone could be very troublesome. As we all know, electronic components are composed by lots of PN junctions. PN could withstand a maximum temperature of 125 ℃, as high as 150 ℃ is rather rare. Temperature higher than it will lead to burn out immediately. The greater the variation in temperature compared to the upper limit, more reliably the power supply will work. This requires the temperature rising of a high frequency switched HV power supply as low as possible.

Loading characteristics is another application behavior for an ESP power source. The power supply not only has to load in a broad dynamic variation range, but also has to bear flashovers as frequent as once a second, another harsh requirement.

The control of ESP power supply differs from that of other HV switching power supply. Conventional HV power supply requires low ripple, high reliability, smooth linearity or easy load control, a kind of voltage source basically. While the HV switching power supply for ESP outputs the way more like the current source behave, meanwhile it could set voltage waveform freely, in a quick response, and withstand frequent sparking.

2 DESIGNING CONSIDERATIONS OF HIGH FREQUENCY SWITCHED HV POWER SUPPLIES

Reports on HV switching power supplies are distinctive. In circuit it may be divided roughly into power input unit, inversion unit, boost rectifier output unit, and power control unit.

2.1 Power Input Unit

Most of power supplies with high power employs 3-phase inputs, uncontrolled 3-phase rectifying, wave filtering. Power factor is improved dramatically compared with mains frequency single -phase power source.

2.2 Power Inversion Unit

Usually H-bridge of four switching tubes is used for power inversion unit. In some cases several low-power high-speed switching tubes in parallel or a few H-bridged inverters in parallel put into operation so as to improve efficiency. And the controlling mode falls into several categories such as pulse-width modulation (PWM), phase shift pulse-width modulation, and pulse frequency modulation (PFM).

PWM has mature quantitative analysis method, it has advantages of excellent power behavior, no returning current in inverter, and of low power loss. Frequency being fixed, the problem caused by electromagnetic interference could be solved easily. But as switching components, it has to suffer from hold-off loss. In past year, it is a real tough job to make high power inverters higher than 20 kHz owing to great cut-off loss of inverting components. As switching components of low loss are getting popularized in recent years, this problem will be settled gradually.

Distributed capacitance is inevitable a HV transformer, using it PWM could also form a parallel resonant inverter to further decrease hold-off loss.

PFM mode works well when high frequency switched HV power supplies are applied in ESP especially on occasion of not demanding too much for ripple, reliability and so on. Leakage inductance of HV transformer is usually rather great, while in PFM inversion circuit, the inductance will construct a series resonant circuit together with additional capacitive inductance. And the output voltage can be varied through changing the working frequency of inverters.

ESP power supplies demands not too much as for ripple, and generally power is relatively high. Series resonant fits quite well for the field. When working at the value less than half of resonant frequency, current peak of inverter is high while the effective value is low, in this case the rising rate of output voltage will be limited in some extent. In addition, characteristic impedance presents not as successive as current does, under same overloading condition and working at the same frequency, the over current of inverters will be too large. Thus, when working around 0.8 times of resonant frequency, the above shortcomings could be settled.

2.3 Boost HV Rectifier Output

For boost rectifier output unit, we adopt step-up transformer and DC voltage-multiplier circuit to acquire the high voltage as desired. When the voltage output is guaranteed we will decrease the output of HV transformer as much as possible based on the following causes: firstly, high turns ratio will affect circuit performance. Secondly, the iron core bank (magnetic core) of high frequency transformers is like a small window, the voltage output should not be limited too much. Thirdly, it is difficult to radiate heat. Based on the fact the high frequency switched HV power supplies discharge too frequently, many efforts have been done, trying to acquire a high voltage as required only by boosting and rectifying, but definitely it is still rather a arduous task to manufacture a high frequency transformer in this way.

2.4 Power Control

As for power control unit, it might be understood into two aspects, one aspect is the control of power supply itself, such as characteristics of constant voltage, constant current, loading adjustment, input control, square wave response, ripple and various protection, etc., the other meaning is to control the power to a value as required, for example, how to make it work at intermittent mode, at a critical value of sparking, how to set the peak and valley values of a voltage, and how to set intermittent duration or the rising time.

3 RESEARCH ON HV SWITCHING POWER SUPPLY OF 400 MA, 80 KV

3.1 Design Specification

Storage temperature: - 40° C to + 70 °C
Working temperature: - 30 °C to + 50° C
Temp rising of power supply: <20 °C
IP class: 55
Input voltage: 3 phase, 380 VAC
Output voltage: 0-80 kVDC (negative)
Output current: 0-400 mADC
Maximum output power: 32 kW
Output voltage ripple: <5%
Power factor: >0.9
Conversion efficiency: >90%

3.2 Technical Solutions

Mechanical unit

The whole system is mounted in a sealed tank to ensure it could work in bad working condition. The high voltage unit is insulated by transformer oil, almost all heat from all of the radiating components have transferred into transformer oil. The HV output unit is located at the bottom of power source, which makes it easier to install and combine all units into a package.

Cooling and radiating

Statistics shows that 80% of switching power supplies failing to work is caused by radiating difficulty, so an effective cooling system is an important guarantee for a power source to operate reliably. Thereby circulated oil cooling is adopted in our power system. What we do is to transfer the heat of important radiating components like IGBT into transformer oil, when oil is cooled, important radiating components will be cooled off, too. So the IGBT module will run safely if only the oil temperature is in control.

Input rectifier unit

A distinguishing feature of our HV switching power supplies is that, in stead of electrolytic capacitors for filtering, which is usually used to reduce output ripples after input rectifying, we adopt quality capacitors of 100uF in our power source. High-powered power sources employ 3-phase inputs, the voltage will arrive to 530 V after rectifying, which is too high for electrolytic capacitors to withstand. In this case, series and parallel connections have to be combined, and more capacitors are needed meanwhile. High-capacity HV electrolytic capacitors are high in price, and another consideration is temperature will greatly affect the lifetime of electrolytic capacitors.

Power inversion unit

Resonant inverters in series are employed with PFM modulation. When in full load, inverter current will enter into a successive status. Though compared to inverters working at non-successive current, the efficiency will be reduced by 1%-2%, the peak current through IGBT will be reduced. Running at non-full-power, the current of inverters will be in a non-successive status, too.

Boost HV rectifier output unit

Voltage-multiplier circuit is applied in order to reduce the HV transformer insulation and decrease the distributed capacitance. Since standard complete iron core could be used here, the winding work becomes extremely easy, system reliability could be ensured and the cost will be reduced too. Meanwhile, only half of full-wave silicon rectifier stack is necessary due to adoption of voltage-multiplier circuit, the HV filtering capacitors costs approximately half of HV rectifier stack. And the expenditure for rectifier unit is similar with full wave rectifiers.

When sparking occurs in electric field, the storage energy of capacitors will be released, one shortcoming of voltage-multiplier circuit. Actually if we calculate sparks by 60 per minute, the average discharging power will be less than 30 watts, less than 0.1% of power rating. Additionally, a kind of special discharging current-limit circuit makes discharge current at 80kV be limited within 200 A, so the influence has been minimized. Additionally the voltage-multiplier capacitors could effectively suppress the over voltage applied on HV silicon stack, which demonstrates its advantages.

Control unit

Here we would only emphasize the control for power source itself. A power supply contains detection loops for input voltage and output current, each has excellent responsive characteristics respectively. Dual PID control of Voltage and current in system could make it work at a constant voltage or constant current. Since the bandwidth after control is far higher than ripple frequency through 3-phase wave filtering, the input rippled will be controlled.

Protection for power supplies

Input: under voltage, lightning over voltage, over current

Output: over voltage, over current, discharging current limit

Inverter: over current, IGBT break, over heat

Transformer oil: over heat, oil level

Safety: interlocking

Based on above concepts we developed power source as following (Figs. 1, 2, 3):

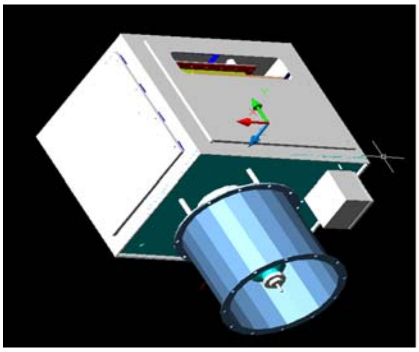

Fig. 1 Model of HV switching power supply

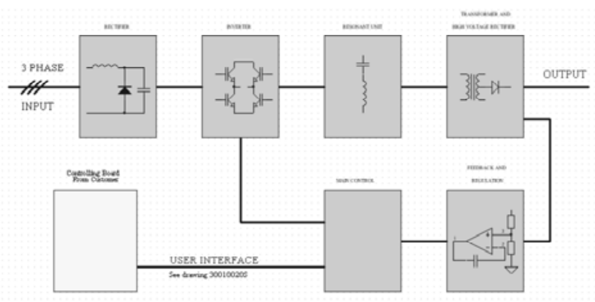

Fig. 2 Block circuit diagram

Fig.3 High frequency power supply in lab

Fig. 4 Slope ramp of HV output

Shown in Fig. 4 is an oscillogram with working voltage of 64 kV (polarity reversed). In this drawing, the total rising time lasts for about 3ms, approximately 20 kV/ms, basically a linear ramp.

Table 1

Ambient temperature	Temperature on IGBT radiator	Maximum transformer oil temp
22 □	38 □	42 □

Table 1 illustrates temp rising data when working stably at full power, from the table we could see the maximum oil temp rising is as high as 20 ℃, even could be as low as half of a conventional T/R, a great favor to enhance reliability.

Extensive experiments have been conducted on HV power supply based on open circuit, short circuit, less load, full or over load, discharging, the result indicates that our power supply could work at any point reliably within voltage range of 0-80 kV and current of 0-400 mA, and meanwhile it can withstand various flashover intensity.

4 CONCLUSIONS

It is a tough job to design a HV switching power supply for ESP due to its own particular characteristics. Thank for many years of experience, our research is proceeding smoothly in general. Two years ago, a prototype power source had been put into operation in a power plant abroad actually, with satisfying running result. Presently great deal of work has been done to improve its performance. Finally we make a conclusion as following based on extensive tests carried out in our laboratory and its operating situation:

1. It is feasible for not applying large capacity of electrolytic capacitors at the input side of power source, and it will benefit for improving the reliability and prolonging its lifetime.
2. Series resonant inverters might be running quite reliably.
3. The voltage rising rate of HV switching power supply is approximately 20 kV/ms.
4. The power source might work at ambient temperature of 50 □ reliably due to relatively low temp increasing, which needs to be proved further.
5. The application of voltage-multiplier circuit will vastly decrease the requirements of designing transformers, and it also plays an important role to improve reliability. The cost will not added, and the fabrication process will be simplified.
6. The power supply will be running steadily within the range of a rectangular area formed by voltages of 0-80 kV, current of 0-400 mA.