A review of different types of power supplies for ESP-energization with respect to ESP performance and mains interaction

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Abstract

There are several different types of power supplies for ESP used in the industry [1]. This paper targets a review of the most common types of ESP power supplies focused on their system impacts, ESP performance and electrical mains, respectively. The analysis include: collecting efficiency, availability, energy efficiency and power feeding requirements.

1 Introduction

There are several different types of power supplies for ESP used in the industry [1]. This paper targets a review of the most common types of ESP power supplies focused on their system impacts, ESP performance and electrical mains, respectively. The analysis include: collecting efficiency, availability, energy efficiency and power feeding requirements.

The mission of an ESP power supply (power converter) is to convert the electrical power supplied from the AC mains (power source) into a controlled high voltage DC current optimized for the operation conditions of the bus section (load). Fig. 1 shows a first example of an ESP energization system consisting of a single phase power feeding from the mains, a power supply, and the ESP bus section. This type of power supply system is often referred to as 'single phase thyristor controlled T/R system'. This technology was introduced in the seventies following the introduction of thyristors which has a controlled turn-on that enables a pulse-by-pulse control of the load current (esp bus-section). The system operates at the frequency of the power source (50/60 Hz).

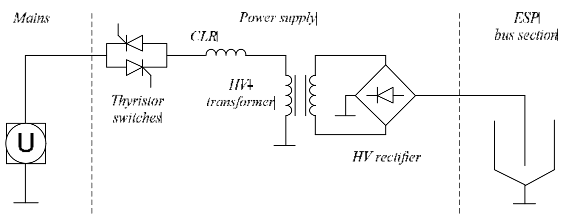


Fig. 1. ESP energization system including power source (Mains), power supply, and load (ESP).

In Fig. 2 a second example of an ESP energization system is given. It depicts a more recently introduced (first installations in 90-ties) [3] type of power supply the high frequency power supply, HFPS, (also referred to as SMPS). This system operates at higher frequency (>20 kHz) in order to very precise control the load current and to eliminate the voltage ripple at the output this to obtain high collection efficiency. In addition it has a very high power factor and energy efficiency. The enabling technology for HFPS was the introduction of IGBTs (Insulated Gate Bipolar Transistor) which can operated efficiently at higher frequencies and allows for control of both turn-on and turn-off of the current.

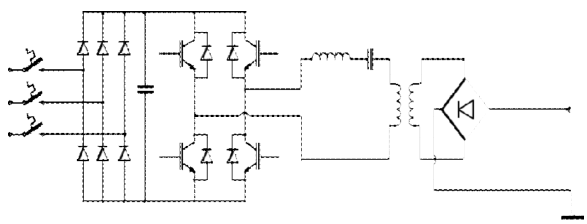
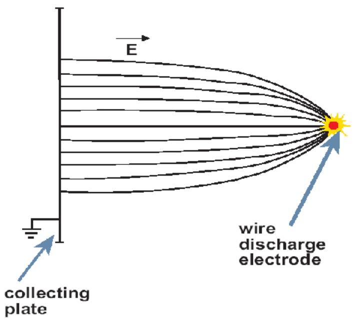


Fig. 2. ESP high-frequency power supply.

Fig 3 (a) shows the general principal of electrostatic precipitation. The flue gas is made to pass between two electrodes, the discharge electrode (DE) and the collecting electrode (CE). A high DC voltage is applied to the electrodes, typically so that the CE is connected to ground and the DE to a negative potential (20-150 kV).The high electrical field close to the DE, fig. 3 (b), initiates a corona discharge, i.e. negative charges are emitted from the DE into the gas flow. The negative charges will drift towards the positive electrode, CE. Some of the charges will stick to particles and make these charged and to drift towards the CE. The collected dust is dislodged by means of mechanical rapping.

(a)



(b)

Fig. 3. (a) Electrostatic dust precipitation, (b) E-field

For system analysis of electrical behaviour of a ESP bus section the circuit model in Fig. 4(c) can be used, where C_{ESP} models the capacitance of the ESP and R_{Cor} (non-linear) models the corona current.

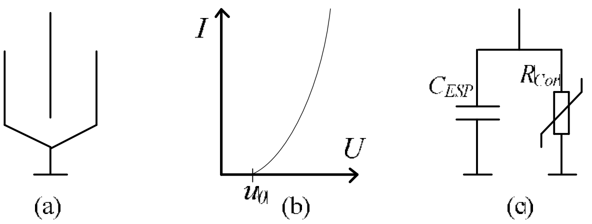


Fig. 4. (a) ESP bus section, (b) U-I characteristic, (c) Electrical model.

The electrical characteristic of an ESP bus section is given by the energy storage in the electrical field, capacitance of the bus-section, and the corona discharge characteristic, the U vs I characteristic. Fig. 4 (b) indicates the corona discharge characteristic, i.e. the VI-curve [5], [6], [7]. In [3] a model of the UI characteristic is given,

$$I = AU(U - M) \quad (1)$$

Where A and M are experimentally determined constants.

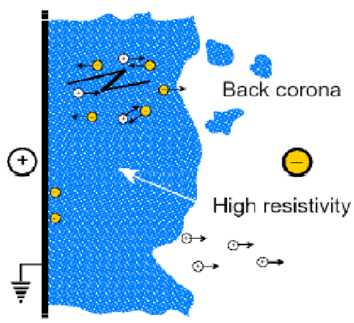
C_{ESP} can be calculated from the energy density, $\frac{dW_E}{dV}$, of the electric field

$$\frac{dW_E}{dV} = \frac{\varepsilon\varepsilon_0 E^2}{2} \quad (2)$$

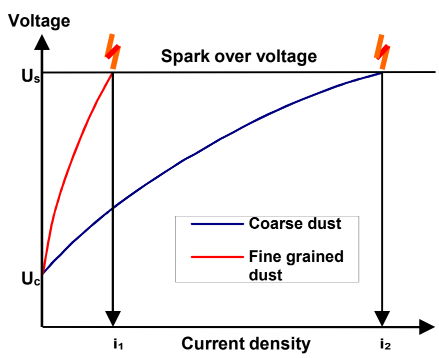
where $\varepsilon\varepsilon_0$ is the dielectric constant of the medium and E is the local field strength.

Fig. 5. indicates two different effects which may limit the ESP performance. In Fig. 5 (a) back corona is shown. This is a result of the electric field in the dust layer exceeding a critical value. At this point local breakdowns in the dust layer occurs, leading the injection of positive charges into the gas. The positive will drift towards the negative electrode and reduce the charging of particles resulting lower collecting efficiency and higher power consumption. Back corona, [x] is the result of high resistivity of the dust. From an energization perspective the remedy to back corona is intermittent energization, IE, which decreases the average dust layer field strength while maintaining an even corona current distribution. IE means that the current to the bus section is pulsed. Fig. 6 indicates emission vs power for back-corona conditions and for non back-corona conditions.

The second effect, corona quenching Fig 5 (b), originates from the space charge in the gas which tends to decrease the field strength close to the discharge electrode. Consequently the corona discharge is reduced and the collecting efficiency of the ESP is reduced. Corona quenching is effected by the size distribution of the dust particles, the more fine dust the more severe corona quenching. To limit this effect a power supply with very low voltage ripple is called for.



(a)



(b)

Fig. 5. (a) Back corona, (b) Corona quenching

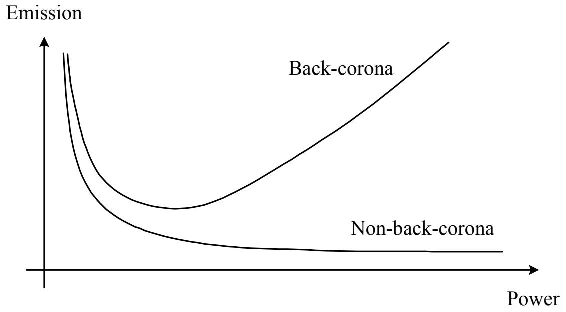


Fig. 6. Dust emission vs power input

2 Review of Power Supplies

In this section the most common types of ESP power supplies will be discussed. These are: thyristor controlled TRs (single- and three-phase), high frequency power supplies, mid frequency power supplies and pulsed power supplies.

Single phase thyristor controlled TR system

Fig. 7 shows the circuit diagram of single phase thyristor controlled T/R system. This power supply system includes a pair of anti parallell thyristors which together with the CLR, Current Limiting Reactor, completes the primary circuit of the step-up transformer. The power input to the system connects to a main voltage of a three phase power grid. The secondry side of the transformer connects to HV-rectifier which feeds the high voltage DC current to the load (ESP bus-section). The output current is controlled by means of phase angle control, α. The turn-on of the thyristor is delayed with respect to zero-crossing of the input voltage. The thyristor is turned-off by the zero crossing of the current. Fig. 8 depicts typical waveforms of the system. The high ripple content of the output voltage should be noted. This limits the corona discharge, given the non-linear characteristic of the VI-curve. Fig. 9 shows the reaction to spark overs. Once the spark occurs the bus section is discharge and voltage goes to zero. This will increase the voltage of the CLR and consequently goes up. The thyristor will turn-off once the current reaches zero which requires a negative input voltage. Hence, the reaction time to a spark over is comparably long, ms range, resulting in relatively energy released in the spark over. Due to the series connection of CLR the reactive power consumption is high, specifically at reduced output voltage.

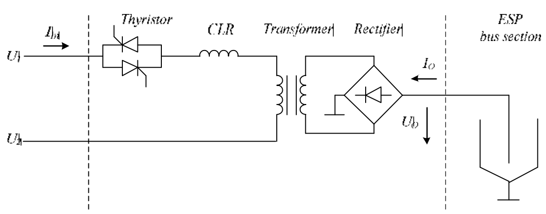


Fig. 7. Single phase thyristor controlled TR system.

Fig. 8. Single phase TR system, typical waveforms.

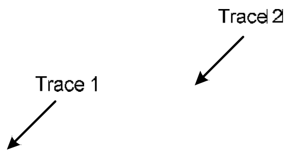


Fig. 9. Single phase TR system, spark over.
Trace 1: I_O, Trace 2: U_O , 2 ms/div

The system operates at the frequency of the power source (50/60 Hz).

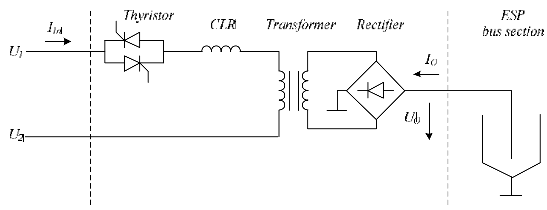


Fig. 10. Single phase TR system, IE (intermittent energization).

Three phase thyristor controlled TR system

The system operates at the frequency of the power source (50/60 Hz).

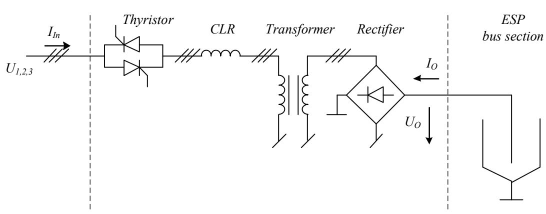


Fig. 11. Three phase thyristor controlled TR system.

High frequency power supply

Fig. 3 depicts a more recently introduced (first installations in 90-ties) [3] type of power supply for ESPs, the high frequency power supply, HFPS, (also referred to as SMPS). This system operates at high frequency (>20 kHz) in order to minimize voltage ripple at the ESP to increase current and consequently the collection efficiency. In addition it has a very high power factor and is three phase fed.

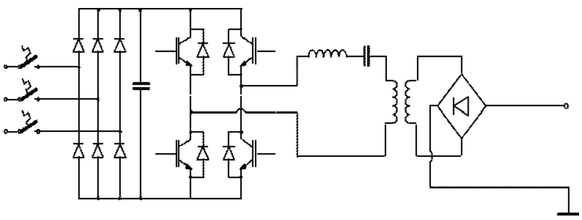


Fig. 12. High-frequency power supply. HFPS

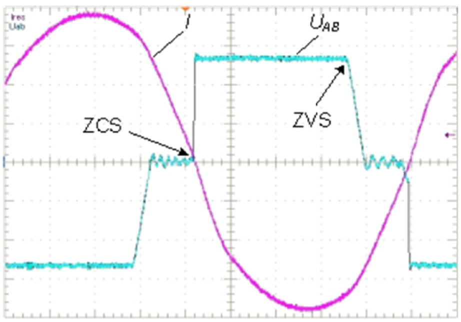
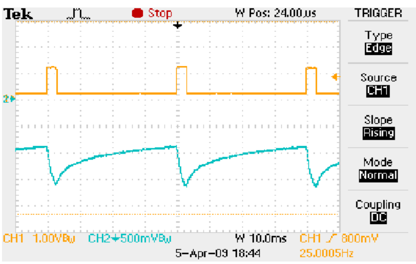
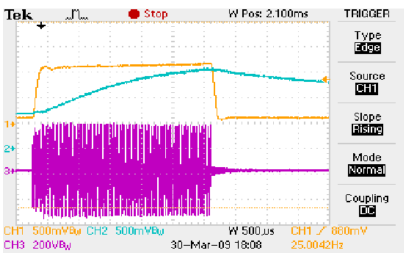


Fig. 13. HFPS, typical waveforms, 25 kHz



(a)



(b)

Fig. 13. HFPS, Intermittent energization.

Mid frequency power supply

Fig. 12 depicts a more recently introduced (first installations in 90-ties) [3] type of power supply for ESPs, the high frequency power supply, HFPS, (also referred to as SMPS). This system operates at high frequency (>20 kHz) in order to minimize voltage ripple at the ESP to increase current and consequently the collection efficiency. In addition it has a very high power factor and is three phase fed.

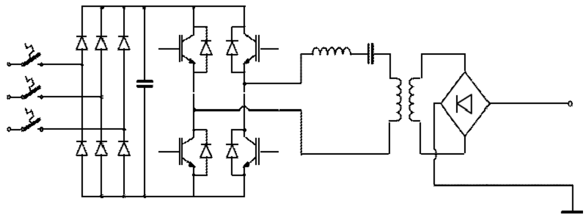


Fig. 14. Mid-frequency power supply.

Pulsed power supply

Fig. 4 depicts a Pulsed Power Supply for ESPs. This type is specifically targeting very high-resistivity dust applications. A short voltage pulse (100 us) is supplied the ESP in order to handle severe back-corona situations.

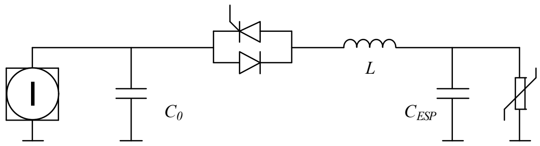


Fig. 15. Pulsed power supply

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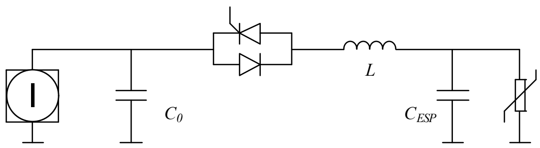

Fig. 16. Pulsed power supply, typical waveforms.

In addition to the examples given above also three phase T/R systems, mid-frequency systems, and low-frequency power supply systems will be analysed.

3 Discussion

In addition to the examples given above also three phase T/R systems, mid-frequency systems, and low-frequency power supply systems will be analysed.

4 Conclusion

In addition to the examples given above also three phase T/R systems, mid-frequency systems, and low-frequency power supply systems will be analysed.

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