A new power regulator control system based on verilog for electrostatic precipitators

Zisheng Zhang*, Guan Li, Taotao Liu, Pengbo Ge, Zhiqiang Liu
Electrostatic Research Institute, Hebei University, No.180 WuSi East Road, Baoding, China
E-mail: zhangzisheng@hbu.edu.cn

Abstract. In order to improve the inefficient response of the power system in traditional electrostatic precipitators, such as long design cycles and low safety, a new power regulator control system is designed to tackle the deficiencies. The working voltage system of an electrostatic precipitator consists of an L-C component, a rectifier bridge group and a step-up transformer. The Verilog hardware description language is used to complete the design of the feedback systems. Continuous steady current can be obtained automatically through changing the number of steady voltage control units. The results show that control systems can accurately feed back the changes of the voltage signal of the electrostatic precipitator. Comparing with other control systems, it has the advantages of faster response, higher accuracy, better monitoring performance and superior anti-interference capacity.

1. Introduction

Comparing with traditional wet and sack-style dust-cleaning apparatus, the electrostatic precipitator has the advantages of high efficiency and cheap operation. The control system of electrostatic precipitator mainly uses integrated circuit and relays as the control unit of electrostatic precipitator, making the line voltage signal could feed back and send an alarm in real time [1]. But because of the integrated circuit’s limitation, especially the interference of the strong feedback signal, has already blocked the development of the control system. We designed a voltage control system with the electronic design automation (EDA) to solve this problem. This method changed the traditional electrostatic precipitator control unit [2]. EDA technology has the incomparable advantage since it uses the modular language, independent description of the structure and the top of the design concept. It uses the Verilog HDL hardware description language to complete the feedback control system in the EDA software platform, and proceeds the logic compile, logic division, and optimization, the logical layout wiring, logic simulation, the logical mapping and programming download, making the system control unit can apply in different type of coal dust environments. The maximum corona voltage and constant current can be obtained through adjusting the L-C steady voltage control unit and silicon rectifier bridge, which ensures the electrostatic precipitator work effectively. At the same time, the feedback signal of high pressure electrostatic precipitator can control the number of L-C steady voltage control unit through the program written by Verilog HDL language so as to achieve the real-time detection and early warning signal voltage [3].

* To whom any correspondence should be addressed.
2. Main circuit design of the ESP

The main functions include two requirements: (1) the design of the working voltage and current of electrostatic precipitator (2) real-time monitoring of voltage and current under the environment and adjustment of operating voltage adaptively. Figure 1 shows the main circuit of the electrostatic precipitator. According to the design standard, the power uses the voltage of 380 V and the working current with a frequency of 50 Hz, and the working current is in the range of 15-20 A. We can get the constant current with L-C steady voltage control unit. Work voltage and current are boosted through the high impedance booster transformer and silicon rectifier bridge group, and applied on the corona electrodes in the electrostatic precipitator. The corona electrodes make the dust in flue gas be electrified, and produce the negative and positive ions. When the dust particles was charged by these ions, dust particles with the positive and negative ions is absorbed by the corona electrode and the collection plates [4]. Analog voltage and current signals are tested by voltage and current detection sensor in this electrostatic precipitator. The Verilog HDL language design of feedback control chip receives the digital switching device into digital signals of the voltage and the current. And through the optimal comparative method, the feedback control chip changes the number of the L-C steady current units in order to achieve safe power supply. If the voltage signal is unusual, this feedback system will alarm and cut off the power automatically, which prevents electrostatic precipitator from damage.

Figure 1. High pressure constant current ESP main circuit.

3. L-C steady voltage control unit

The L-C steady voltage control unit is composed of inductance and capacitance. Capacitance and inductance present a pure resistance because of their storage characteristics. It makes the reactive power of control system reduce to the minimum so as to achieve the stable current and voltage. When the electrostatic precipitator system develops into the short circuit, the L-C steady voltage control unit can absorb the power energy. And it protects the electrostatic precipitator system itself. At the same time, the feedback control unit of the electrostatic precipitator increases or decreases the number of the L-C steady voltage control unit for realizing the regulation of the voltage and the current.

Figure 2. LC parallel resonant circuit module and two port model.
According to two port network theory and two port model (G11, G12, G21, G22 are plural coefficient, RL is the equivalent load, RL impedance) we can put forward:

\[
\begin{align*}
\vec{U}_1 &= Z_{11}\vec{I}_1 + Z_{12}\vec{I}_2 \\
\vec{U}_2 &= Z_{21}\vec{I}_1 + Z_{22}\vec{I}_2
\end{align*}
\]  

(1)

According to the two port models, we can get the formula of the input/output voltage and current:

\[
\begin{align*}
\vec{U}_1 &= G_{11}\vec{U}_1 + G_{12}\vec{I}_2 \\
\vec{I}_1 &= G_{21}\vec{U}_2 + G_{22}\vec{I}_2
\end{align*}
\]  

(2)

According to the superposition theorem, U1, U2 should be equal to the sum of their voltage:

\[
\begin{align*}
\vec{I}_2 &= \frac{\vec{U}_1}{G_{12} + G_{11}R_L} \\
\vec{U}_2 &= \frac{\vec{U}_1 G_{21}}{G_{12} + G_{11}R_L}
\end{align*}
\]  

(3)

If LC chooses the appropriate value and connecting method, G11 will be 0. The load current is determined by the voltage and G12, which is irrelevant to the impedance.

If the input voltage is Usin, we can get the load current.

\[
\vec{I}_2 = -j\frac{\vec{U}_1}{2\omega L} + R_L(\omega^2 LC - 1)
\]  

(4)

When the circuit produces resonance, according to \(\omega^2 LC - 1 = 0\), we can get:

\[
\vec{I}_2 = -j\frac{\vec{U}_1}{2\omega L}
\]  

(5)

We can see that the load current is unrelated to the load size, and it is only related to the resonance frequency and the internal matching in the LC module. According to the resonance theory, the size of the resonant frequency only depends on the value of capacitor and reactor. Therefore, when the number of the LC module is determined, the circuit’s output current will be stable. Similarly, U2 is related to RL.

4. Feedback control unit

The voltage and current signals from the sensor are received by the feedback control unit, in order to achieve the effect of tracking the feedback. The feedback control unit regulates the number of the L-C steady voltage control unit in an optimal way to make the electrostatic precipitator operate safely. It uses the Verilog HDL hardware description language to complete the feedback control system in the EDA software platform, and proceeds the logic compiled, logic division, and optimization, the logical layout wiring, logic simulation, the logical mapping and programming download, achieving the simulation. Because of the characteristics of simulation and flexibility, the feedback control system can keep efficient removal efficiency of dust, and adapt to different dust environments [5].

Figure 3 shows the feedback control unit circuit. The feedback control circuit mainly includes the frequency divider, the comparator and the counter. Its macroscopic principle is that in the unit time, the control unit realizes the feedback control by comparing the output work voltage and the rated voltage. If the input voltage is greater than the rated voltage, the comparator will count. When the voltage signal is greater than the rated voltage, the number of the counter will be more than 4, the feedback control unit alarms and cuts off the power, in order to protect the electrostatic precipitator. The microscopic description is: The power signal produces the clock signal through the frequency divider. By comparing the size of the rated voltage U1 and the work voltage U2, the feedback control unit realizes the real-time control of the voltage signal. When U2>=U1, the comparator outputs the high electrical level, and makes the counter start count. If the counter counts 4 times in 20s, the counter will produce the alarm signals. On the contrary, when U2<U1, the comparator outputs the low electrical level, the counter resets, and the electrostatic precipitator will work normally [6].
Because the detection unit sampling and the protection potential signal are all below 12v, this paper is based on the 4-bit comparator to compare the rated voltage and work voltage in order to realize the signal input of the counter.

The reset signal makes the “out” of the counter be “1100”, and the “cout” of the counter be “0”. When the clock signal of the counter comes, the counter adds 1, and by parity of reasoning. When the counter counts 4 times in 20s, the counter outputs the alarm signal (“cout”=1). We use the signal of 50Hz as the divider’s input signal. By 250 frequency divider’s frequency division, the cycle of the clock signal will be 5s.

5. The simulation and download of the control unit
The design adopts Altera Company’s software (Quartus) for program’s compiles and simulation, and then we download the program to the SOPC chip for the experiment simulation. When the rated voltage a > the work voltage b, the “Load” of the comparator will be 0. On the contrary, when the rated voltage a <= the work voltage b, the “Load” of the comparator will be 1. When the clock signal comes, we compare the signal a and b. If the work voltage is greater than the rated voltage, the comparator outputs the high electrical level, and the counter starts to count. If the counter counts 4 times continuously, the electrostatic precipitator alarms and cuts off the power. The results of the simulation are shown in Figure 4.

The function of the divider is to get the required clock cycle. On the basis of our field experimentation, the frequency of 50Hz is the best clock signal. Choosing this clock signal, we can not only keep the efficiency of the dust removal, but also protect the electrostatic precipitator [7]. As the Verilog HDL language changes the traditional control method, and makes the experiment accomplish successfully. The divider’s results of simulation are shown in Figure 5.
Using the SOPC chips for the analog control, we can realize the real-time monitor. If the electrostatic precipitator has an accident, the feedback control unit can detect and alarm. The experiment results are shown in Figure 6. The electrostatic precipitator reaches the work voltage in 10s. If the environment has the first breakdown, the voltage appears arc, and the feedback control system controls the numbers of the L-C steady voltage control unit. In this way, the work voltage of the electrostatic precipitator declines to 45kv. When the fourth breakdown happens in the electrostatic precipitator, the feedback control unit cuts off the power supply and alarms [8].

6. Conclusion
The design of the electrostatic precipitator’s intelligent control system can complete requirements of experiments. A complete electrostatic precipitator power feedback system integrated in a chip (SOPC) has more advantages than the classical electronic design method. This design uses the computer software to improve the design efficiency. Through the test, the feedback control unit can track the changes of the electric field and output the best voltage. This feedback control unit improves the alarm ability and dust removal efficiency of the electrostatic precipitator, and it is faster than the electric precipitator feedback unit which is controlled by PLC. It’s especially suitable for the dust removal equipment in thermal power plant, so it has a broad application prospect in the market.

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