Programmable power supply design based on biological factor interference mechanism

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Abstract: Nowadays, how to deal with the water pollution has become a worldwide problem. More and more people are focusing on how to disinfect and reuse water resources. In daily life, people often use chlorine gas to disinfect, but chlorine gas disinfection has low efficiency and it will take a long time to be effective. It is also easy to form secondary pollution. Therefore, ultraviolet disinfection technology is more and more popular. At present, ultraviolet disinfection technology generally adopts fixed output frequency and voltage, and the effect is not good. This is because VBNC is a common state of water organisms, in which water organisms are in a special state of dormancy. When the external environment is restored properly, they can still recover their activity. Here, a programmable power supply based on DSP is designed to solve this problem. If the ultraviolet lamp is powered by this power supply, the output voltage and frequency can be variable. The system greatly improves the sterilisation efficiency, and the effective sterilisation can reach 99.99%.

1 Introduction

1.1 VBNC of aquatic organisms
The full name of VBNC is viable but non-culturable [1, 2]. Bacteria will enter this state in some undesirable conditions [3]. Studies have shown that UV disinfection at a dose of 60 mJ·cm⁻² can effectively remove 99.9% of culturable E. coli and Salmonella. However, this dose of UV disinfection has lower removal rates of active E. coli, Salmonella, and mycobacteria. This is caused by a large number of pathogens entering the active but non-cultivable (VBNC) state [4]. As of the oligotrophic characteristics of water, the percentage of VBNC state in water organisms can reach up to 98% [5]. In this state, aquatic organisms also have activity, the metabolism is very low, and they are in an uncultured state. They do not have the ability to form colonies. Aquatic organisms can still complete normal physiological activities such as respiration and gene transcription at this time. The aquatic organisms in VBNC state can return to normal state when the external conditions are restored, and the reproductive capacity can be restored. The process of recovering aquatic organisms from VBNC state to normal state is called resuscitation. Due to the characteristics of ‘Play Dead’ of VBNC bacteria, conventional methods cannot kill them effectively, which brings great public health risks [6].

1.2 Ultraviolet disinfection principle
Ultraviolet ray is an electromagnetic wave with a wavelength of 100–380 nm. It is divided into four bands. The ultraviolet band that can sterilise and disinfect is 200–280 nm. Here, 253.7 nm is the best wavelength band for ultraviolet disinfection [7]. Ultraviolet disinfection is to destroy the microbial genetic material DNA, interfere with its replication and transcription, so that it loses its reproductive ability and then inactivates it. Ultraviolet disinfection has the advantages of high disinfection efficiency, no secondary pollution, broad spectrum and so on [8]. Many studies have shown that ultraviolet disinfection is feasible for sewage disinfection, and its disinfection effect can achieve chlorine disinfection effect, or better. Ultraviolet disinfection has no side effects, nor does it produce by-products after disinfection. Therefore, the water treatment technology is increasingly recognised by people. At present, the ultraviolet disinfection technology is generally used by mains input after rectification and voltage stabilisation, outputting fixed voltage and frequency to supply power to ultraviolet lamps, and then disinfecting water [9]. As of VBNC state of aquatic organisms, the disinfection of ultraviolet disinfection technology is not complete, which is also one of the biggest problems existing in ultraviolet disinfection at present.

1.3 Summary of this system
Ultraviolet disinfection has the advantages that chlorination disinfection does not have, but because water organisms have the characteristics of VBNC, the ultraviolet disinfection system needs to be improved, so that ultraviolet rays emitted by ultraviolet lamps can disturb the protection mechanism of water organisms, and sterilisation and disinfection are more thorough. Here, the power supply of UV lamp is improved, which is a 0–1000 V adjustable DC power supply and regulates the frequency modulation by adjusting PWM. The following functions can be realised:

a. Keeping the output frequency constant and the output voltage changing, thereby controlling the irradiation intensity of the ultraviolet lamp to change;
b. Keeping the output voltage constant and changing the output frequency, thereby controlling the irradiation intensity of the ultraviolet lamp to change;
c. Both the output voltage and the output frequency can be changed, thereby controlling the irradiation intensity of the ultraviolet lamp to change.

2 Hardware design
2.1 Design of core board
The core processor designed here is TMS320F28335 chip produced by TI, which is a high-performance 32-bit floating-point DSP core processor with many advantages such as high main frequency, strong operational performance, and rich peripherals [10]. With the development of science and technology, the digital power supply has gradually replaced traditional analogue power supply. Therefore, the chip is used here.

The power chip used in the core board power module is TPS767D301. This chip has 5 V input, and it has dual output which can be independently powered. One output voltage is fixed at 3.3 V, and the other output voltage can output an adjustable power supply of 1.5–5.5 V. The voltage used here is 1.9 V. In order
to get the voltage without burrs and spikes, it is also necessary to filter with capacitors [11]. As shown in Fig. 1, it is the schematic diagram of the core board power supply circuit.

The clock module is the basis of the whole system. Considering the need of simple and reliable clock design, crystal and internal oscillator are selected here. The reset circuit is designed in two modes: manual reset and power-on reset. In addition to the above modules, a JTAG download interface and a pin jack are required.

2.2 Design of bottom board

The bottom board comprises a human–machine interaction module, various interfaces, an RS232 module, a buzzer circuit, and a driving circuit. The human–machine interaction module here consists of two parts: keyboard and HMI touch screen. Two input modes of touch screen input and key input can be realised. The main function of buzzer circuit is alarming and prompting. When the system is abnormal, the buzzer will chime and give an alarm, and when the relay is turned on or off, it will chime and give a prompt. Triodes mainly play a role in switching here, and resistors mainly play a current limiting role, and the loudness of buzzers can be changed by changing the resistance value of resistors. The function of diode D9 is to prevent the polarity of the power supply at both ends of the buzzer from being reversed, which is a protective measure.

The PWM drive circuit is the core part of the bottom board. The main function of PWM drive circuit is to drive MOSFET on and off [12]. In practice, in order to reliably turn on and off the MOSFET, the applied voltage needs to slightly exceed the threshold voltage. Therefore, the high level is designed to be 12 V, and the low level selects the negative voltage. The voltage stabilising module of this circuit uses LM2596S voltage stabilising chip. Its input is 24VDC and output is 18VDC. In order to ensure the reliability of MOSFET on and off, it needs to be handled. Such that the output is +12 V at high level and −6 V at low level. In order to prevent interference, photocoupler TLP250 is also used here. The schematic diagram of the drive circuit is shown in Fig. 2.

2.3 Design of middle-level board

The middle board includes a power conversion circuit, a power acquisition circuit, and a relay module. Here, the power input 220VAC is used to obtain the working voltage of each module through the rectifier and the stable voltage of various stable voltage chips. The main voltage types are: 24VDC, 5VDC, 12VDC, and 15VDC. Among them, 24VDC is used in PWM drive module, and it is regulated to 18VDC on PWM drive module. One of 5VDC is used to maintain the operation of the relay. 15VDC is used for acquisition module. The 15VDC output through the L7812

2.4 Buck circuit design

In order to enhance the anti-interference performance of the system, Buck circuit is designed on a single board. Considering that the input of DC can reach up to 1000 V, the MOSFET of Buck circuit chooses STW4N150 with the highest withstand voltage of 7912 voltage stabilising chips is 12VDC, which is used for dual power supply of the operational amplifier LF353. In order to check whether each voltage stabilising module works normally, each module is connected with light-emitting diodes. A current limiting resistor is also connected in series. The schematic diagram of the power conversion circuit is shown in Fig. 3.

In order to better monitor the operation of the system, it is necessary to add acquisition modules of input and output voltages. Through DSP processing, the data are finally transmitted to HMI touch screen. The acquisition module uses LF353 operational amplifier chip. This chip is a two-stage amplifier with dual power supply. In order to make the later data processing more convenient, no amplification processing is carried out, so that LF353 plays a role of voltage following. The function of voltage follower is to amplify the input voltage and output stable voltage, and the maximum switching current can reach 3A. Its isolation voltage can reach up to 7 kV. The parameters and performance of this relay can completely meet the requirements. The schematic diagram of the relay module is shown in Fig. 5.

When GPIO59 outputs a low level, one and two pins of photocoupler TLP521 conduct, five and six pins conduct, and one pin of triode Q4 receives a high level, one and two pins of triode Q4 conduct, and two and three pins conduct. One and two pins of the relay conduct. The three and four pins of DAT200–24 are the power supply, and the power supply voltage is 24 V DC. Triode Q4 plays a switching role in this circuit. As shown in Fig. 6, it can be seen that two relays are used in the input and output of Buck circuit respectively.
1.7 kV. The diode is SF1600-TR. The capacitor is 1.2 kV electrodeless polypropylene capacitor. The schematic diagram of Buck circuit is shown in Fig. 5. The resistance series partial voltage method is adopted for voltage sampling. Both input and output are controlled by relay [13]. The schematic diagram of Buck circuit is shown in Fig. 6.

3 Software design

PWM module, AD conversion module, and serial port module are mainly used in the system. The DSP is initialised conventionally at first, and then it enters the while loop. Module detection, parameter adjustment, PWM output adjustment, and Buck circuit output are carried out in turn, and then AD collects voltage information and feeds it back to the touch screen to see if the system works normally. If it works normally, the above process will be cycled. If it runs abnormally, it will alarm and stop running. The flow chart is shown in Fig. 7.

4 Results

The voltage ranges of 50, 100, 200, 300 and 400 V are tested at 10 kHz, respectively, and the characteristics. Comparing the characteristics of output voltage and power supply efficiency at different frequencies, different duty ratios, and different input voltages.

According to Figs. 8 and 9, we can find that the output voltage will rise with the increase of duty ratio, and there is approximately a positive proportional relationship. With the increase of input duty ratio, the output power, and power supply efficiency are also increasing.

In order to observe the change trend of ultraviolet intensity with the output voltage more intuitively, this paper uses an irradiator to measure the ultraviolet radiation quantity at different frequencies, different input voltages, and different duty ratios.

According to Tables 1–3, it can be found that when the frequency and duty ratio are constant, the irradiation quantity increases with the increase of voltage. When the input voltage and frequency are constant, the irradiation quantity increases with the increase of duty ratio. When the input voltage and duty ratio are constant, the irradiation quantity increases with the increase of frequency. The main factor among these three factors is the input voltage, and the relative influence of frequency and duty ratio is relatively small. In addition, the height of ultraviolet lamp is also a very important influencing factor, and the height is inversely proportional to the irradiation quantity [14].

5 Conclusion

Conventional ultraviolet disinfection lamps can only output ultraviolet rays with fixed frequency intensity [15]. The system proposed here provides a variety of variable power supply for ultraviolet lamps. When the position of ultraviolet lamp is fixed, the voltage, frequency, and duty ratio can be changed randomly, making the output voltage, frequency and the like randomly variable, thus achieving the purpose of disturbing VBNC state of aquatic organisms.
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Fig. 8 Output voltages of different input voltages at 10 kHz

Fig. 9 Power supply efficiency of different input voltages at 10 kHz

Table 1 Irradiation quantity corresponding to different input voltages when frequency 5 kHz and duty ratio are 50%

| Input voltage/V | 150      | 200      | 300      |
|----------------|----------|----------|----------|
| Irradiation quantity/W cm⁻² | 0.1105   | 0.1567   | 0.2179   |

Table 2 Irradiation amount corresponding to different input voltages when the frequency is 5 kHz and the input voltage is 300 V

| Duty ratio | 10%    | 50%    | 90%    |
|------------|--------|--------|--------|
| Irradiation quantity/W cm⁻² | 0.2237   | 0.2251  | 0.2392  |

Table 3 Irradiation quantity corresponding to different input voltages when the input voltage is 300 V and the duty ratio is 50%

| Frequency/kHz | 1      | 5      | 10     |
|---------------|--------|--------|--------|
| Irradiation quantity/W cm⁻² | 0.2146   | 0.2213  | 0.2249  |