Optimization Study of High-Efficiency Rectifier Circuits for Uninterruptible Power Supply Systems

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Abstract. Uninterruptible Power Supply (UPS) is a kind of equipment that can supply power to other equipment's in an uninterrupted way, which can ensure that the key equipment's can continue to operate stably in the face of power grid failure. Therefore, uninterruptible power supply system is of utmost importance in the modern power system. The aim of this paper is to optimize rectifier circuits in uninterruptible power supply system that rely on three-phase bridge full-wave rectifier circuits. Build a model using LTspice and simulate it, compare and analyze the waveform characteristics of the output voltage of the load under different filtering schemes, and propose optimization strategies based on actual production. As one of the key components of the UPS system, the rectifier circuit can directly affect the efficiency with stability of the whole system. Hence, it is important to optimize the high efficiency rectifier circuit to improve the overall performance of the UPS system.

Keywords: UPS, filtering, three-phase bridge full-wave rectifier.

1. Introduction

UPS is the electrical device that combines surge protections with battery backups. The UPS's primary function is to supply power to connected devices without interruption, as stated in its name [1]. It can convert low-quality AC power into high-quality AC power to supply equipment with special requirements for power quality, and it can also convert power in storage devices such as batteries into high-quality AC power to supply equipment that requires continuous power supply [2]. With the continuous improvement of industrial automation and information technology, the role played by the uninterruptible power supply system becomes more important in modern power systems. It ensures the continuous and stable operation of critical equipment in the face of grid faults or power quality problems, and its reliability and efficiency have become the focus of research.

As one of the key components of the UPS system, the rectifier circuit directly affects the efficiency and stability of the entire system. Therefore, optimizing the high efficiency rectifier circuit is of great significance to improve the overall performance of the UPS system. This paper investigates the efficient optimization of rectifier circuits in uninterruptible power supply systems, simulates the basic three-phase bridge full-wave rectifier circuits through LTspice simulation. And devotes to the reduction of harmonic pollution of the system and the improvement of waveform smoothing through the comparative analysis of the waveform characteristics to summarize the innovative design schemes and optimization strategies.

Firstly, this article introduces the background of UPS system and its operation process, the basic working principle of rectifier circuit. Subsequently, this paper uses LTspice to simulate and draw the preset circuit, run and derive the output voltage waveform. On this basis, the impact cause by various factors on the rectifier circuit's performance is demonstrated through theoretical analysis and experimental verification. In addition, considering the complexity and cost-effectiveness in practical applications, this paper discusses the practicality and economic benefits of the proposed scheme, and looks forward to the development prospect of UPS systems. In summary, the goal of this letter is to optimize the rectification link in the uninterruptible power supply system through scientific analysis and innovative design, to improve the overall performance and to meet the stringent requirements of modern society for the efficient and stable operation of power systems.

2. Basic principles

2.1. Basic structure of the UPS system

Under normal operation, the AC power input from the grid will be charged by the rectifier and the battery pack at constant voltage and current limit. When there is an abnormality in the high-voltage alternating current input to the grid (power failure or beyond the allowable variation range), the battery pack in the UPS system will replace the rectifier to input steady direct current to the inverter. The rectifier will continue to charge the battery pack and then automatically switch to the normal float charge state after the input of grid returns to normal state. The system that was suggested has three converters, which include an input converter (AC-DC), an output converter (DC-AC), and a charge-discharge converter (DC-DC) [3]. Figure 1 shows the operation process of UPS system.

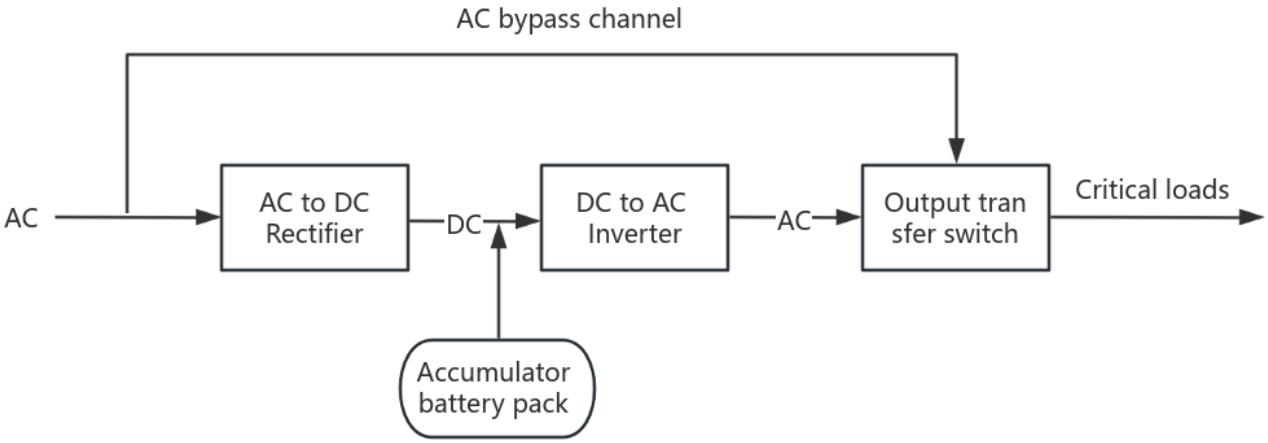


Fig. 1 Operation process of UPS system (Photo/Picture credit: Original)

Rectifiers, as the interface of the device grid, occupy a considerable proportion of the power electronic devices [4]. As the first part of the UPS system, the organizer plays a crucial role in the operation of the system.

2.2. Features of UPS

2.2.1. UPS Units have the ability to prevent blackout and surge

Damage or failure in electronic devices are often caused by issues with electrical distribution. The UPS system has a backup DC power supply function, which can provide a stable and uninterrupted power supply for the equipment during the power outage period. At the same time, the system has the protection function of instantaneous power grid disconnection, in which there is no inverter conversion time in the online type. Thus, the stability of the electronic equipment can be improved.

2.2.2. UPS units are designed to prevent power unstable and drops of voltage

The UPS is the certain filtering function, which can filter out some power grid interference signals and play the role of purifying power supply. At the same time, the system has the protection function of instantaneous power grid disconnection, in which there is no inverter conversion time in the online type. The UPS system also has an AC regulator function, so it is possible to use the system without the need for an additional AC regulator.

In essence, UPS systems act as a shield against the unpredictable nature of power supplies, safeguarding both the operational efficiency. The function of allowing for an uninterrupted operation of connected devices is particularly important for hospitals, data centers, and industries where even a brief power outage can have catastrophic consequences. In the ubiquitous of electronic devices today, the importance of ups gradually prominent. Therefore, the letter will discuss how to improve the operation efficiency of the uninterruptible power supply system.

2.3. Rectification and inverter

2.3.1. Rectification

The process of rectification is process of converting alternating current (AC) to Direct current (DC). In this process, the flow of current in only one direction is permitted while in the other direction is resisted due to the presence of the diodes.

The three-phase bridge fully controlled rectifier circuit which the experiment based on is composed of the transformer, the common cathode group, the common anode group and the load, the common cathode group has VT1, VT3 and VT5, VT4, VT6 and VT2 [5]. Because this circuit adopts 6 semi-control device thyristors, the trigger circuit is designed to make the circuit work normally (this study uses pulse voltage to trigger the thyristor conduction). When the circuit works normally, a common cathode group and two thyristor of a common anode group are needed to connect simultaneously at each time [4]. In order to ensure that the thyristors are turned on sequentially, the circuit is triggered by double pulses. There is phase difference between the pulses of VT1 and VT2, VT1 and VT3, while the output voltage ripples 6 times per cycle, so the rectifier circuit is also called a 6-pulse rectifier circuit [6].

This topic is based on the three-phase bridge full control rectifier. Three-phase rectification is the process of converting three-phase AC power supply to DC voltage, that is, the input power supply of sinusoidal voltage and frequency is converted to DC power supply of fixed voltage, that is, the AC power supply to one-way power supply.

2.3.2. Inverter

An inverter is used to convert direct current (DC) into alternating current (AC). And this process is called the inverse .The core principle is that several special switching elements(like transistors or MOSFET), are turned on or off in a specific sequence to produce an output in the form of alternating current. However, the MOSFET's intrinsic diode leads to further reverse recovery losses and destructive voltage overshoots after the forced switching unit is activated during the dead time [7]. Classical single-phase bridge inverters and SPWM bridge inverters are widely used in sine wave inverters and UPSs [8]. This paper focuses on the impact of optimization of three-phase bridge rectifiers on the efficiency of UPS operation, so it will not be further developed here.

3. Simulation results and the analysis

3.1. Pure load three-phase bridge fully controlled rectifier circuit

In a three-phase AC cycle, Six SCRs were turned on in sequence, allowing the current from each phase to flow to the load, resulting in a DC output. The conduction order is VT1-VT2-VT3-VT4-VT5-VT6.And the open time of each SCR is related to its phase angle α.By adjusting the α, we can control the amount of the DC voltage that has been output. Figure 2 shows the figure of the pure load rectifier circuit that be mentioned.

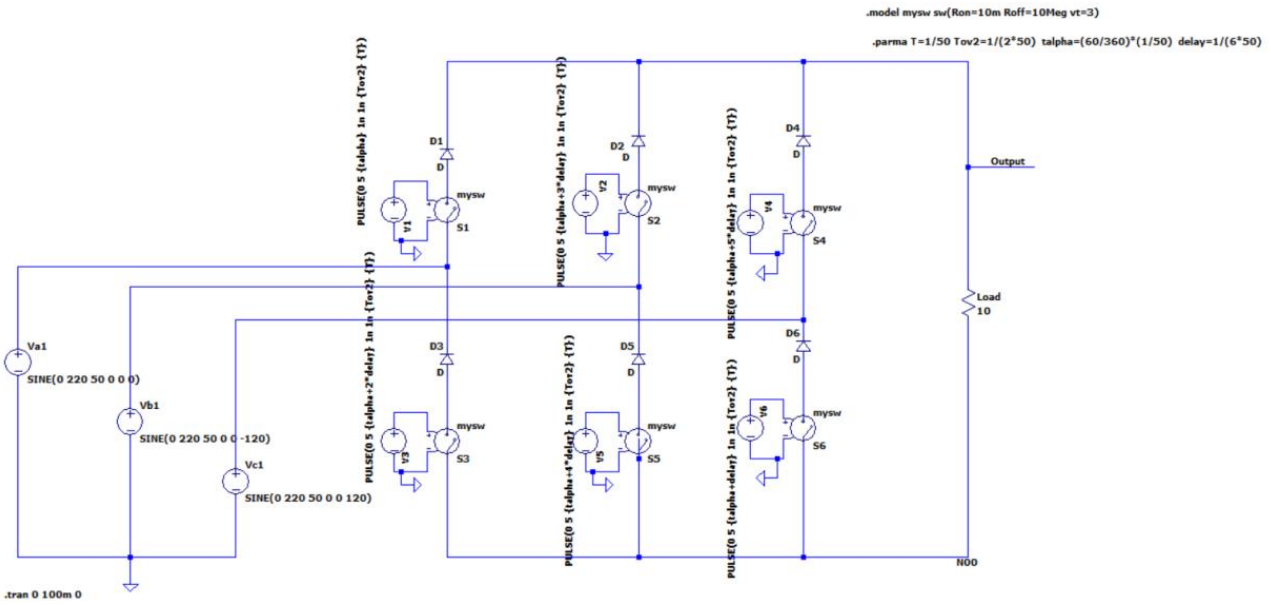
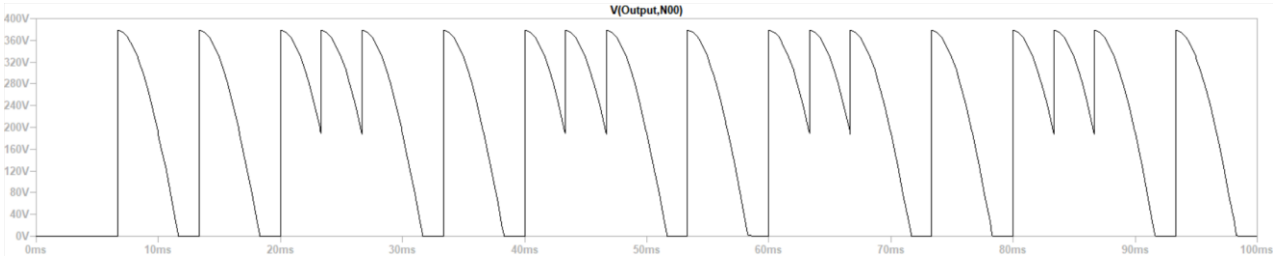
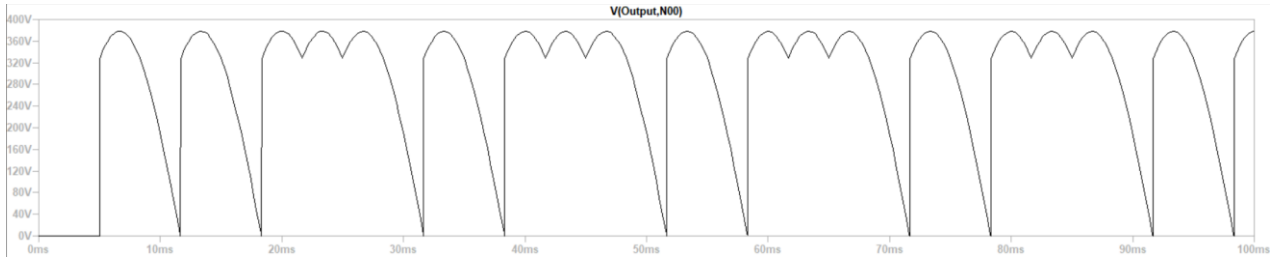


Fig. 2 Rectifier circuit with pure load (Photo/Picture credit: Original)

And the voltage output images under different alpha are shown in figure 3.



(a)α=60deg R=10



(b)α=30deg R=10

Fig. 3 Voltage waveform across the load (Photo/Picture credit: Original)

With phase angle α = 60deg, when the voltage in a certain phase decrease to 0, the SCR in that phase naturally turns off. Although the voltage of the next phase reaches its maximum at this time, the gate trigger pulse of this phase does not start, resulting in the SCR not conducting normally. This results in a situation where the SCRs of all phases do not conduct. It takes until α = 60° for the SCR of the next phase to conduct, thus resulting in a discontinuous output voltage. When α = 30deg, the six SCRs take turns to conduct exactly, and the waveform of voltage is in a critical continuous state.

The waveforms of the load show that the output voltage pulsation increases with the phase angle α. It presented at α=30 degrees are significantly gentler than that at α=60 degrees. Meanwhile, due to the presence of α, the moment of onset of thyristor conduction is delayed, and the waveforms of each segment of the line voltage that makes up Ud are consequently delayed, resulting in a reduction in the average output voltage value. Therefore, the mean of the output voltage shows a negative correlation trend with the change of α.

3.2. RL three-phase bridge fully controlled rectifier circuit

The inductance prevents the alternating current from passing and allows the direct current to pass normally. The reason is that the resistance of current paths is the resistance of the wire when the DC signal passes through the coil. The pressure drop generated by the process is small, the DC signal can pass smoothly. Relatively, as the AC signal passing through, the magnetic inductance coil will produce an inductive electromotive force itself. And the direction of its inductive force opposites to the one of voltage applied, which against the passage of alternating current, so as to achieve the purpose of filtering.

A fully controlled rectifier circuit for RL three-phase bridges is depicted in the figure 4.

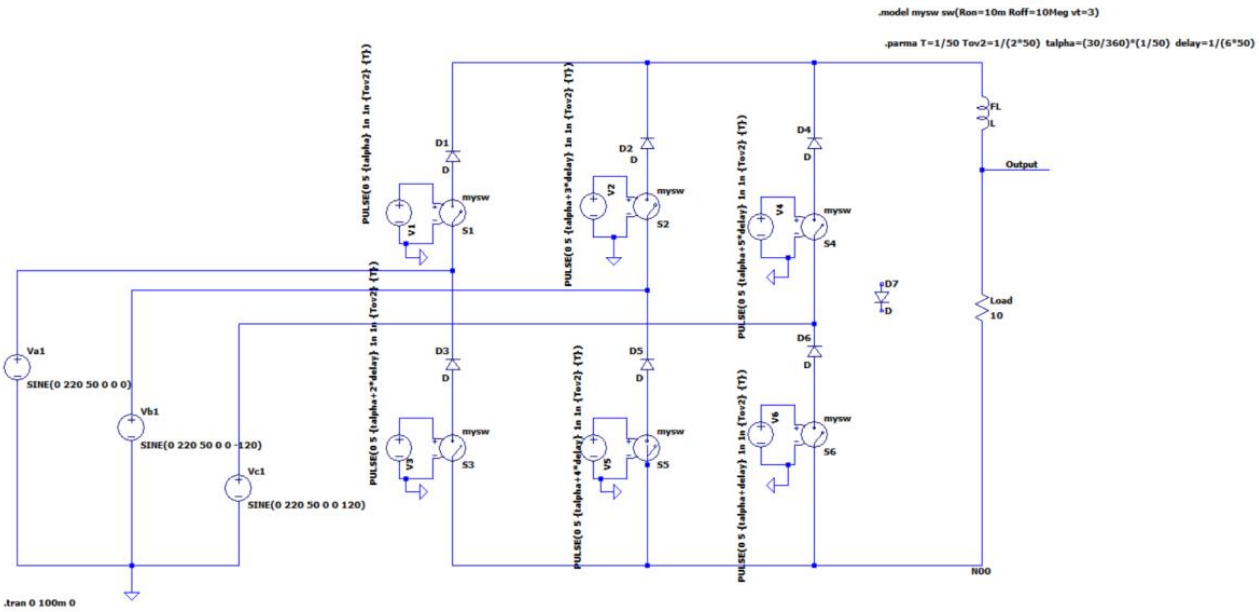
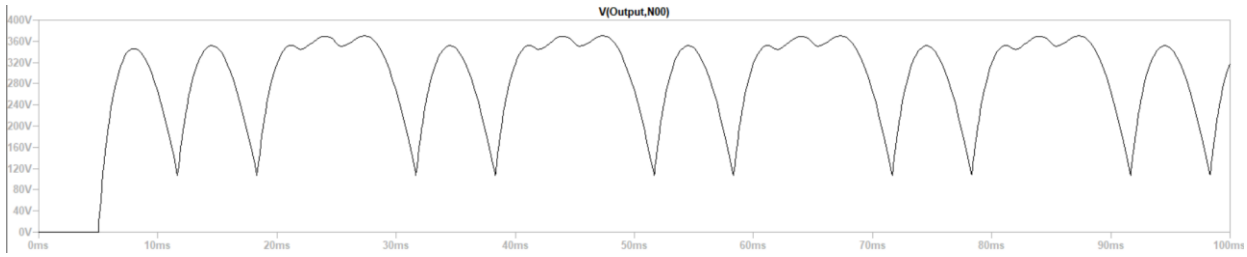
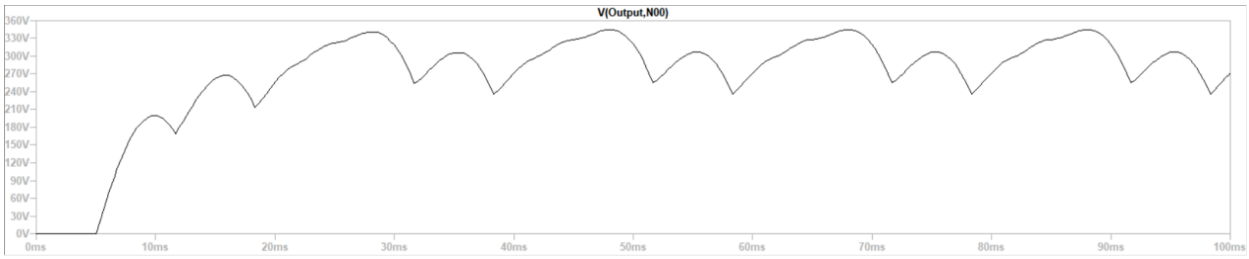


Fig. 4 Circuit with RL (Photo/Picture credit: Original)

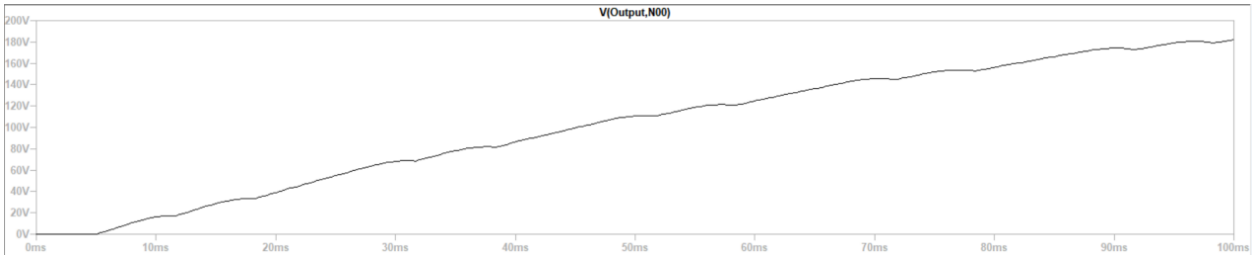
And the voltage output images with different inductance values are shown in figure 5.



(a)α=60deg R=10 L=10mH



(b)α=60deg R=10 L=50mH



(c)α=60deg R=10 L=1H

Fig. 5 Voltage waveform across the load (Photo/Picture credit: Original)

By comparing the above three waveforms, it is obvious that the larger the inductance, the less the ripple. Thus, it can be confirmed that filter inductance in rectifier circuit has the function to smooth DC output and reduce ripple voltage and current. Such a smooth output improves the overall stability of the power supply, making it less vulnerable to sudden changes in the load or the input voltage.

However, while increasing the filter effect, the increase of the inductor will also lead to some problems. First, the larger the inductor means the larger the series impedance, and the greater the pressure drop in itself when the current changes. This effect (especially under high load conditions) will reduce the efficiency of the rectifier. A larger inductance produces better filtering, but at the cost of a larger physical size and potential cost, which is cannot be ignored in the industrial production.

3.3. RC three-phase bridge fully controlled rectifier circuit

In a capacitor filter circuit, with one pair of diodes is activated, the output DC voltage is identical to the biggest one of the AC side line voltages. which supplies both the capacitance and the load [4]. When there is no diode conduction, the capacitor is discharged to the load, and the capacitance voltage Ud drops exponentially [4]. Thus, the result of reducing the rectification voltage pulsation is achieved. The smaller the rectification voltage pulsation is, the better the rectification effect is. In figure 6, the fully controlled rectifier circuit for the RC three-phase bridge is shown.

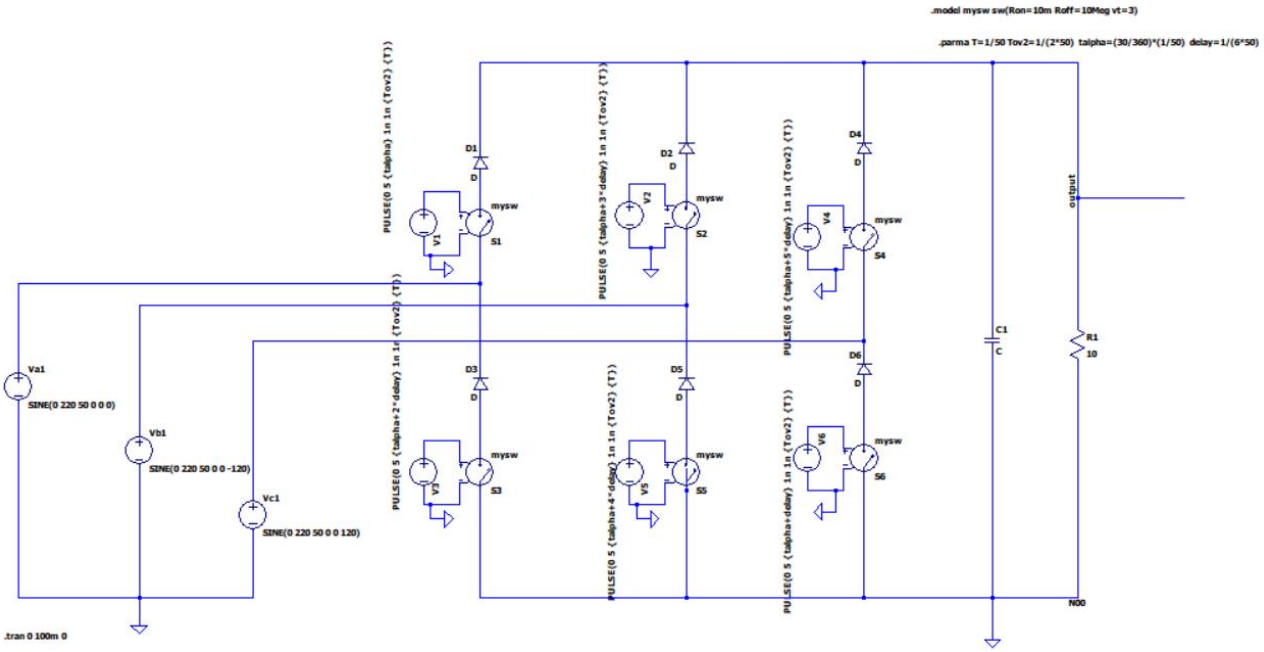
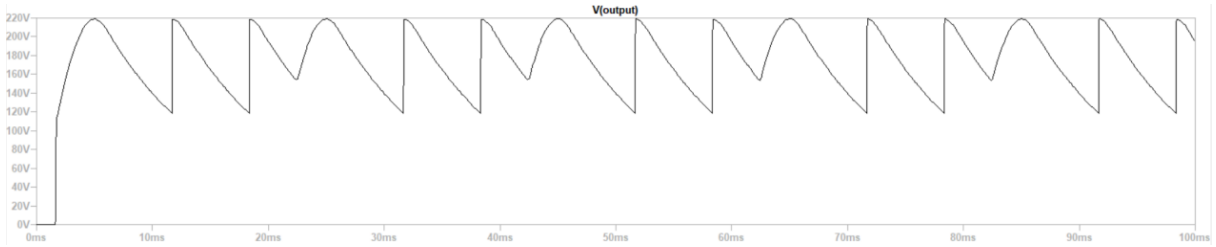
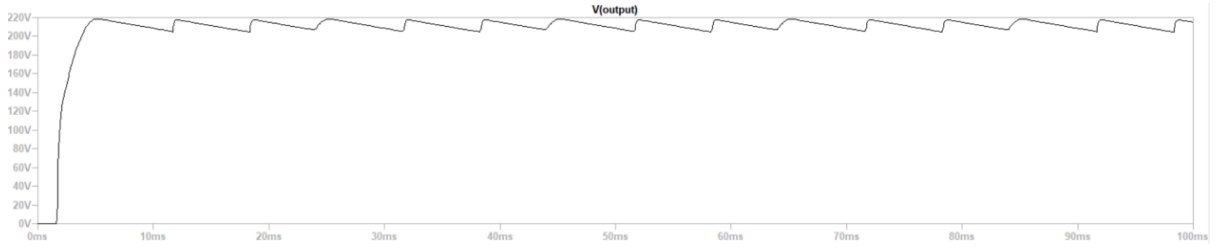


Fig. 6 Circuit with RC (Photo/Picture credit: Original)

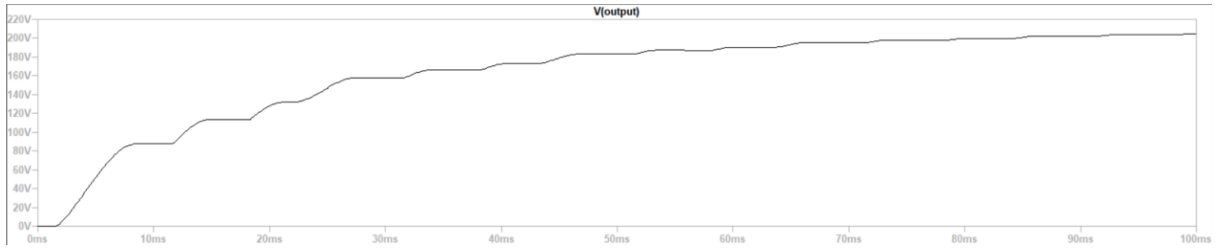
The voltage output images with different capacity values are shown in figure 7.



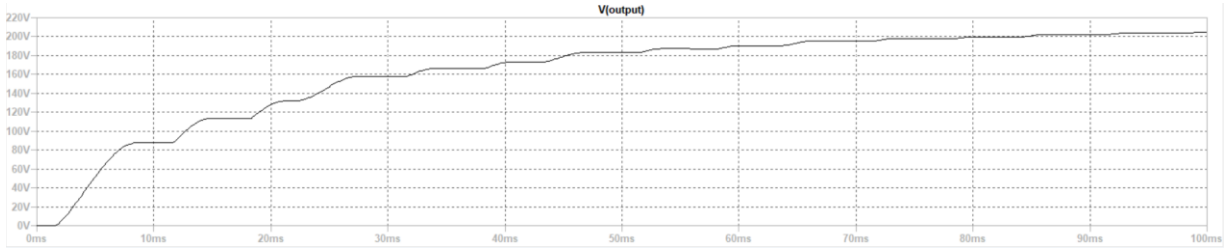
(a)C=1mF



(b) C=10mF



(c) C=1F



(d)C=5F

Fig. 7 Voltage waveform across the load (Photo/Picture credit: Original)

As the capacitance of the capacitor changes from 1 mF to 1 F, the waveform of the output voltage gradually smooths out, while there is no obvious change in the waveform when the capacitance increases from 1F to 5F.

It is not difficult to infer from the output waveform image that within a certain range, the fluctuation of rectified voltage is obvious with the change of capacitance, and decreases with the increase of filter capacitance. But the larger the filter capacitor is not the better, because when the capacitor increases to a certain value, not only to improve the voltage waveform, but it is not economic [9].

3.4. RC pi-type

π -type RC filter circuit is a composite filter circuit, it is mainly composed of two filter capacitors and a filter resistance composite. The capacitor is connected at the two ends of the resistance which makes the circuit look like the letter π. The capacitance plays the main filtering role in this circuit. The use of π-type RC filters for low-pass filtering of the input signal can effectively can reduce the interference signal [10].

The voltage output from the rectifier circuit is first filtered by C1, filtered out most of the AC signals, and then entered into the filter circuit composed of R1 and C2, and further filtered by C2 to output a smoother voltage waveform. The RC π -type filter circuit is shown in figure 8.

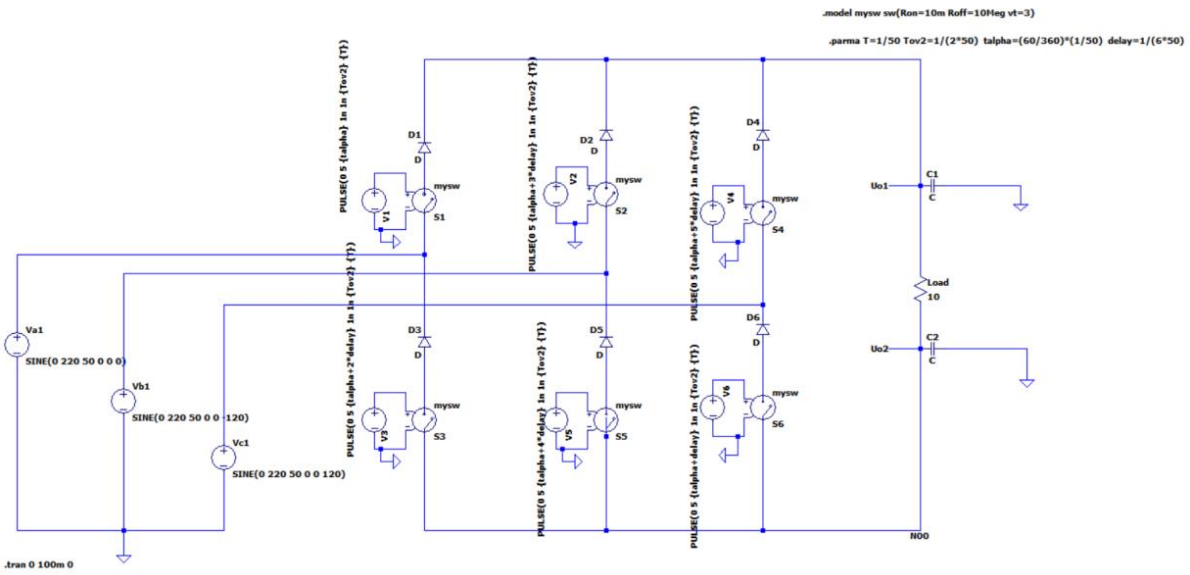
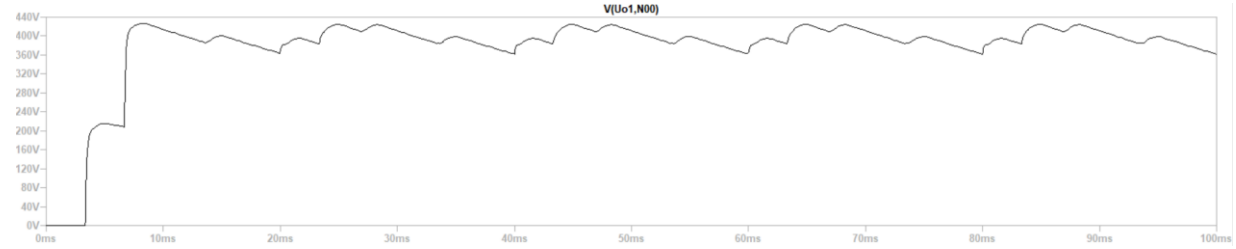
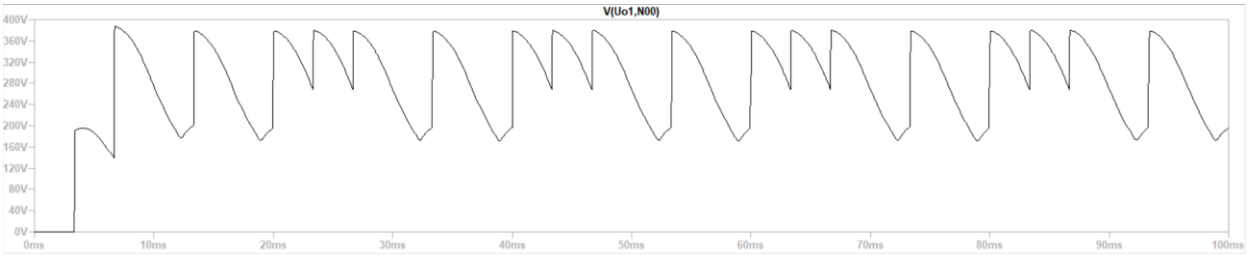


Fig. 8 RC π -type filter circuit (Photo/Picture credit: Original)

And the voltage output images with different capacity values are shown in figure 9.



(a)C=10mF



(b)C=1mF

Fig. 9 Voltage waveform across the load (Photo/Picture credit: Original)

From the waveform, the first turning point is the charging phase of C1. Once it is charged, the voltage filtered by it will been send to the next element.

Comparing the filter capacitance capacity in the circuit is 10 mF and 1m voltage output waveform respectively, it can be seen that when the capacitance capacity increases, the filtering effect of the circuit is also be improved.

3.5. comparative analysis

Filter capacitors and inductors can significantly improve rectified voltage waveforms within a certain range and can therefore be connected in circuits as high-quality filtering devices. However, when the size of inductors and capacitors exceeds a specific range, their addition may cause a reduction in rectifier efficiency. Compared to filter resistors, filter inductors can cause a smaller voltage drop when AC power passes through, reducing the voltage loss in the rectification process.

4. Conclusion

This paper concludes from the above simulation study as follows: The magnitude of the phase angle affects the rectified voltage output waveform. When the phase angle $\alpha = 30°$, the output waveform reaches the continuity threshold, and then the waveform is no longer continuous in the phase shift range (0-120°). The larger α is in the phase shift range, the larger the pulsation of the output voltage waveform. Within certain limits, the larger the inductance and capacitance, the better the filtering effect in the rectifier circuit, but also at the expense of dynamic response, efficiency, etc. And larger parameters also mean larger physical size and potential cost. For example, while a filter inductor is more effective than a filter resistor in protecting voltage amplitude, its cost is much higher than that of a filter resistor, and this needs to be taken into account in actual production.

As an energy storage facility that can serve loads during power shortages, UPS systems are able to maintain the proper functioning of various critical and infrastructural facilities. The size of the wireless uninterruptible power supply (UPS) storage means its durability in case of emergency, so the energy storage technology of UPS is gradually increasing its position in the development of power systems. The increase in the value of the capacity of energy storage means that UPS development prospects are broad, the development of opportunities to increase at the same time also means that the challenge. How to improve the capacity of the UPS energy storage system as well as the space utilization will become an issue that needs to be discussed in depth.

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