Homework 9

Page 178. Chinese textbook Question 9.1

A lamp is supplied by a single-phase AC voltage controller. Suppose this lamp is a resistor load, the output power reaches maximum value when $\alpha = 0$. Try to find the delay angle α when the output power is 80% and 50% of maximum output power.

Question 9.2

An AC voltage controller is supplied by a 50Hz-220V voltage source, and its load is series resistor and inductor where $R = 0.5\Omega$ and L=2mH. Try to derive:

① Available range of delay angle α

② Maximum value of RMS value of load current,

③ Maximum value output power together with power factor on the source side,

④ When $\alpha = \pi/2$, the RMS value of current in the thyristor, the conduction angle of thyristor and power factor on the source side.

Question 9.3

What is the highest output frequency of an AC-AC converter? Which factor limits the output frequency?

Question 9.4

Explain the basic principles, advantages, and disadvantages of matrix converter circuits. Why are these circuits considered to have promising development prospects?

Answer 9.1

When $\alpha = 0$, we can know that the maximum output voltage should equal to:

$$U_{o\max} = U_I \sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi - \alpha}{\pi}}_{\alpha = 0} = U_I$$

$$P_{\max} = U_{\max} I_{\max} = U_{\max}^2 / R$$

Therefore, when the output power is 80% of maximum output power:

$$0.8 P_{\max} = \frac{\left(\sqrt{0.8}\, U_{o\max}\right)^2}{R}$$

$$U_o = \sqrt{0.8}\, U_{o\max} = \sqrt{0.8}\, U_I$$

Based on the relationship between output voltage and input voltage, we can see:

$$\sqrt{0.8}\, U_I = U_I \sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi - \alpha}{\pi}}$$

Solving this equation, we can see:

$$\alpha = 60.54°$$

So the same applies when the output power is 50% of maximum output power:

$$U_o = \sqrt{0.5}\,U_{o\max} = \sqrt{0.5}\,U_I$$

$$\sqrt{0.5}\,U_I = U_I\sqrt{\frac{1}{2\pi}\sin 2\alpha + \frac{\pi-\alpha}{\pi}}$$

Solving this equation:

$$\alpha = 90°$$

Answer 9.2

1)

We can know the impedance angle φ from:

$$\varphi = \arctan\left(\frac{\omega L}{R}\right) \approx 51.4°$$

Therefore, the available range of α should be:

$$51.4° < \alpha < 180°$$

2)

When the output power reaches the maximum value, the output current and output voltage will reach their maximum values correspondingly.

$$U_{o\max} = U_I = 220V$$

$$I_{o\max} = \frac{U_{o\max}}{\sqrt{(\omega L)^2 + R^2}} = 273.98\,(A)$$

3)

The maximum value of output power and power factor can be calculated as:

$$P_{o\max} = I_{o\max}^2 R = 37.532\,(KW)$$

$$PF = \frac{P_{o\max}}{U_i I_{o\max}} = 0.62267$$

4)

Based on the relationship between delay angle and impedance angle,

$$\sin(\alpha + \theta - \varphi) = \sin(\alpha - \varphi)e^{\frac{-\theta}{\tan\varphi}}$$

$$\alpha = \pi/2,\ \varphi = 51.4°$$

We can solve the equation above, and see:

$$\theta = 133.488°$$

Therefore, the effective value of thyristor current would be calculated as:

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$$I_o = \sqrt{2}\,I_{VT}$$

Then we can calculate the Power Factor on the source side as:

$$PF = \frac{I_o^2 R}{U_I I_o} = \frac{\sqrt{2}\,I_{VT} R}{U_I} = 0.396$$

Answer 9.3

To sum up, with higher output frequency comes more numbers of impulses of two sets of converters which make up the whole AC-AC cycloconverter. Taking the widely-used six-impulses three-phase bridge rectifiers of the cycloconverter as an example, the maximum output frequency should be no less than 1/3~1/2 of line frequency. When the line frequency reaches 50 Hz, the limit frequency of the AC-AC cycloconverter is around 20 Hz.

When the output frequency increases, the grid voltage segments within one period of output voltage decreases and the distortion rate of waveform increases. The current waveform distortion, as well as the torque ripple of the motor, are the main factors limiting the output frequency.

Answer 9.4

Principle:

Chopping the waveform of single-phase or three-phase input AC voltage, the frequency and magnitude of output voltage can be changed. This chopping process can be achieved through varying the delay angle and duty cycle of different switches.

Advantages:

Output voltage is sinusoidal wave, and the output frequency is not limited by the grid frequency. Input current can also be sinusoidal wave and has the same phase as input voltage. Therefore, the power factor on the source side can be either 1 or less than 1. The power can be transmitted in both directions, which can achieve the four-quadrant working process for the AC motor.

Disadvantages:

There are up to 18 switching devices in this converter. The topology of the circuit is complicated, and the cost is relatively high. The control method is not mature yet. Besides, the maximum ratio of output voltage over grid voltage can only reach 0.866, which is rather low.

Promising future:

Compared with the widely used AC-DC-AC cycloconverter, despite six more switching devices, the matrix converter saves the cap on the DC side. Correspondingly, the volume can be decreased. Therefore, it is easy to achieve integration and power modularization. With the rapid advancement of current device manufacturing technology and the rapid development of computer technology, matrix frequency conversion circuits will have great development prospects.