LAB 9

LAB 9: Three-Phase Full Wave Rectifier

Part 1. Three-Phase Full Wave Uncontrolled Rectifier

Part 2. Three-Phase Full Wave Full Controlled Rectifier

SECTION NUMBER :………………………………………

GROUP NUMBER :……………………………….…………

GROUP MEMBERS :……………………………………….
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Part 1. Three-Phase Full Wave Uncontrolled Rectifier

Three Phase full wave uncontrolled rectifier circuit is more complex and expensive than half wave. However there are advantages of low ripple voltage, smooth output voltage waveform, no dc component introducing into input current of each phase, and high efficiency of power conversion.

With this lab you will understand the characteristics of three phase full wave uncontrolled rectifier, measure the voltage and current values .

BEFORE COME TO THIS LAB, YOU SHOULD

* Read the technical background on the report.
* Make some research on Three Phase Full Wave Uncontrolled Rectifier.

AFTER COMPLETING THIS LAB, YOU SHOULD

* Know the circuit of Three Phase Full Wave Uncontrolled Rectifier.
* Know the waveforms of Three Phase Full Wave Uncontrolled Rectifier.

REQUIREMENTS

* Isolating Transformer * Differential Amplifier * RMS Meter * Resistor Load Unit * Inductive Load Unit * Oscilloscope * Wires	* Current Transducer * Power Diode Set * Fuse Set

Experiment 3-2
Three-Phase Full-Wave Uncontrolled Rectifier

OBJECTIVE

1. To understand the operating principle and characteristics of three-phase full-wave uncontrolled rectifier.
2. To compare the advantages and disadvantages between three-phase half-wave uncontrolled rectifier and three-phase full-wave uncontrolled rectifier.
3. To measure the voltage and current values of three-phase full-wave uncontrolled rectifier.
4. To verify the characteristics of three-phase full-wave uncontrolled rectifier.

DISCUSSION

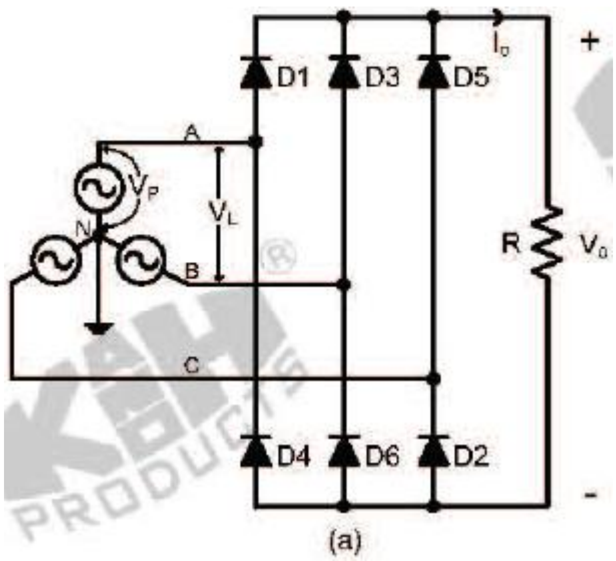
Compared to the three-phase half-wave uncontrolled (or diode) rectifier, the circuit construction of the three-phase full-wave uncontrolled (or diode) rectifier (or simply three-phase full-wave rectifier) is complex and expensive, but it has advantages of low ripple voltage, smooth output voltage waveform, no dc component introducing into input current of each phase, and high efficiency of power conversion.

Figure 3-2-1 illustrates the circuit and waveforms of the three-phase full-wave diode rectifier with a purely resistive load. This figure shows the three-phase power source in positive phase sequence, that is, V_B lags V_A by 120°, V_C leads V_A by 120°. From the phasor diagram, line voltage is equal to $\sqrt{3}$ times the phase voltage, line-to-line voltages V_{AB}, V_{BC}, V_{CA} lead phase voltages V_A, V_B, V_C by 30°, respectively. During the $\pi/6 \leq \omega t \leq 3\pi/6$ interval, the voltage V_{AB} is maximum, therefore diodes D1 and D6 conduct, the output voltage $V_O=V_{AB}$; during the interval $3\pi/6 \leq \omega t \leq 5\pi/6$, the voltage V_{AC} (reverse polarity of V_{CA}) is maximum, diodes D1 and D2 conduct, and the output voltage $V_O=V_{AC}$. In the same manner, during the $5\pi/6 \leq \omega t \leq 7\pi/6$ interval, the voltage V_{BC} is maximum, diodes D2 and D3 conduct so that the output voltage $V_O=V_{BC}$.

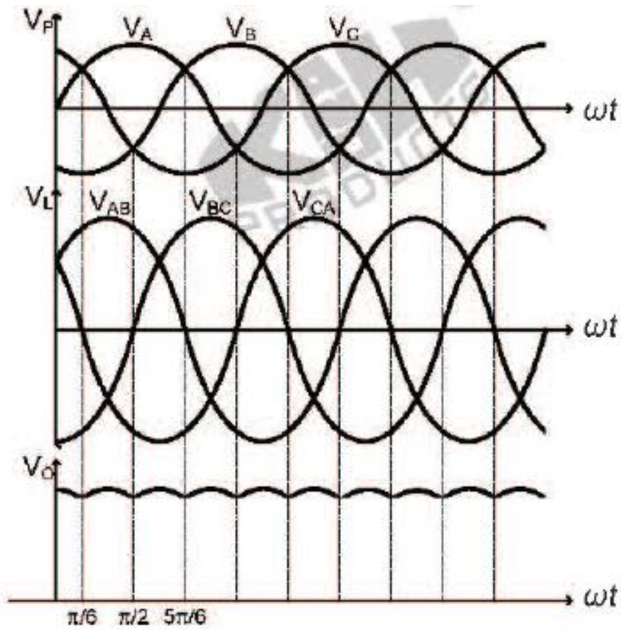
From the voltage waveforms of Figure 3-2-1(b), the frequency of the ripples on the output voltage is 6 times the ac source frequency so that this rectifier is also called the six-pulse rectifier.

In order to describe the characteristics of three-phase full-wave diode rectifier, the symbols and abbreviations are defined as follows:

V_p : Phase voltage
V_L : Line voltage
$V_{P(max)}$: Maximum phase volatge
$V_{P(rms)}$: rms phase voltage
$V_{L(max)}$: Maximum line voltage
$V_{L(rms)}$: Average line voltage
$V_{o(av)}$: Average output voltage
$V_{o(rms)}$: rms output voltage
$V_{r(rms)}$: rms ripple voltage
$I_{o(av)}$: Average output current
$I_{o(rms)}$: rms output current
$I_{d(av)}$: Average diode current
$I_{d(rms)}$: rms diode current
$P_{o(av)}$: Average output power
$P_{o(rms)}$: rms output power
η_r : Rectifier efficiency
λ : Ripple factor
PIV : Peak inverse voltage of diode



(a)



(b)

Figure 3-2-1 Circuit and waveforms of three-phase full-wave diode rectifier with purely resistive load

Many characteristics of the three-phase full-wave diode rectifier with purely resistive load, such as $I_{d(av)}$, $I_{d(rms)}$, $I_{O(av)}$, $I_{O(rms)}$ and PIV, can be descried using the same equations of the half-wave diode rectifier. Other important characteristics of the full-wave diode rectifier are expressed as follows:

$$V_{O(av)} = \frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{6}}^{\frac{3\pi}{6}} \sqrt{3} V_{P(max)} \sin\omega t d(\omega t) = 1.654 V_{P(max)} \quad (3\text{-}2\text{-}1)$$

$$V_{O(av)} = 2.34 V_{P(rms)} = 1.35 V_{L(rms)} \quad (3\text{-}2\text{-}2)$$

$$V_{o(rms)} = \sqrt{\frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{6}}^{\frac{3\pi}{6}} (\sqrt{3} V_{P(max)} \sin \omega t)^2 d(\omega t)} = 1.6554 V_{P(max)} \quad (3\text{-}2\text{-}3)$$

$$P_{o(av)} = \frac{{V_{o(av)}}^2}{R} \quad (3\text{-}2\text{-}4)$$

$$P_{o(rms)} = \frac{{V_{o(rms)}}^2}{R} \quad (3\text{-}2\text{-}5)$$

$$\eta_r = \frac{P_{o(av)}}{P_{o(rms)}} = \frac{1.654^2}{1.6554^2} = 0.9983 = 99.83\% \quad (3\text{-}2\text{-}6)$$

$$\lambda = \frac{V_{r(rms)}}{V_{o(av)}} = \frac{\sqrt{V_{o(rms)}^{2} - V_{o(av)}^{2}}}{V_{o(av)}} = \frac{\sqrt{1.6554^{2} - 1.654^{2}}}{1.654} = 4\% \qquad (3\text{-}2\text{-}7)$$

EQUIPMENT REQUIRED

1. PE-5340-3A Isolating Transformer x1
2. PE-5310-5B Fuse Set x1
3. PE-5310-5A Power Diode Set x3
4. PE-5310-3A R.M.S Meter x1
5. PE-5310-2B Differential Amplifier x1
6. PE-5310-3C Resistor Load Unit x1
7. PE-5310-3E Inductive Load Unit x1
8. PE-5310-2C Current Transducer x1
9. Digital Storage Oscilloscope (DSO) x1
10. Connecting Wires and Bridging Plugs

PROCEDURE

1. Put modules PE-5310-5A, PE-5310-5B, PE-5310-3A and PE-5310-2B in Experimental Frame. Place DSO, PE-5310-3C and PE-5340-3A modules on workbench. Complete the connections shown in Figure 3-2-2 using bridging plugs and connecting wires.

2. This rectifier operates from a three-phase four-wire 220V (phase voltage = 127V) and the load circuit is a 200Ω resistor connected in series with a 200mH inductor. The CH1 of DSO is used to measure the phase voltage V_A via Differential Amplifier Ch.A, and CH2 is used to measure the output voltage via Differential Amplifier Ch.C.

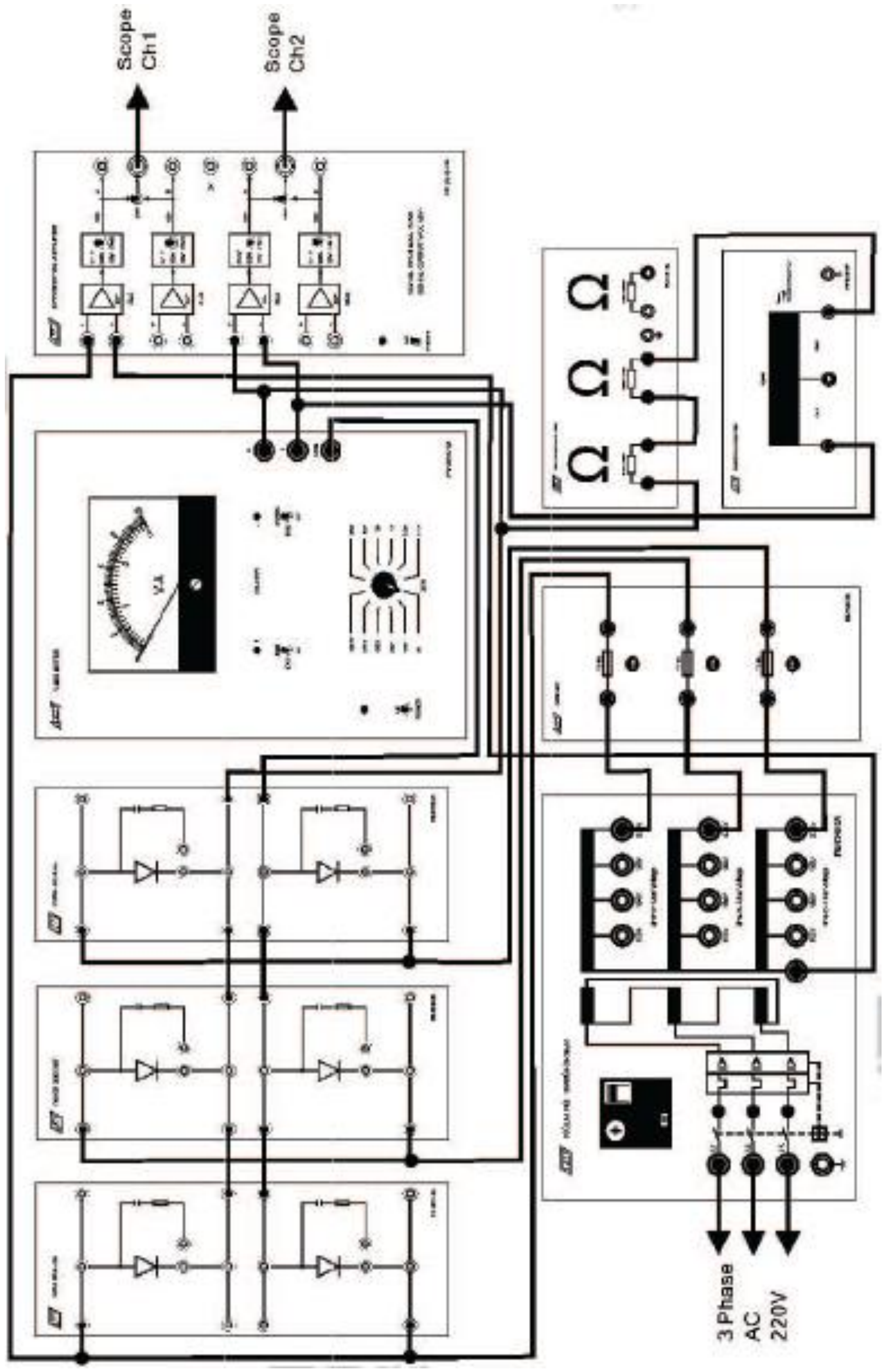


Figure 3-2-2 Wiring diagram for three-phase full-wave diode rectifier experiment

3. Short out the load inductor by placing a connecting wire directly across the inductor terminals. This modifies the load to a purely resistive load circuit. Set the V Range selector(SWA,SWC) switches of Differential Amplifiers Ch.A and Ch.C to 500V. Using DSO, measure the phase voltage V_A (CH1) and load voltage (CH2) waveforms of the three-phase full-wave diode rectifier as shown in Figure 3-2-3. Measure the peak value of phase voltage $V_{P(max)}$ =_____V, the frequency of ripple on output voltage is _____ times the input source frequency.

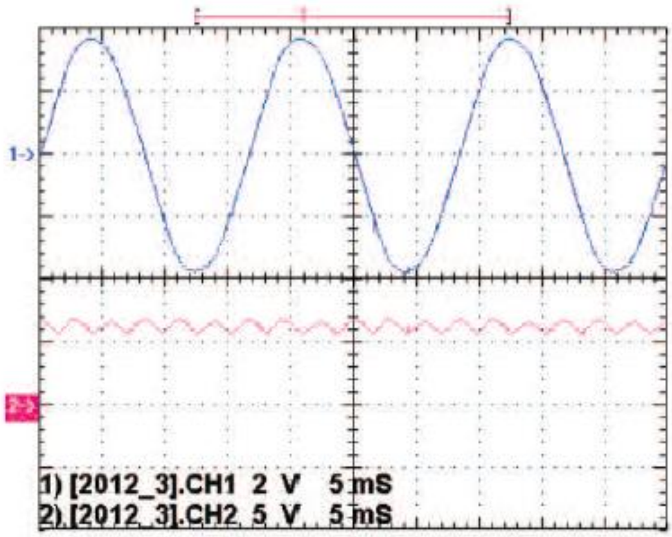


Figure 3-2-3 Measured phase voltage V_A (CH1) and load voltage (CH2) waveforms of three-phase full-wave diode rectifier with purely resistive load

4. Place the AC+DC/AC(SW2) and RMS/AV(SW1) selector switches of RMS Meter in AC+DC and AV positions. Measure the average output voltage $V_{O(av)}$ =_____V and the average output current $I_{O(av)}$ =_____A of the rectifier. Place the AC+DC/AC(SW2) and RMS/AV(SW1) selector switches of RMS Meter in AC+DC and RMS positions. Measure the rms output voltage $V_{O(rms)}$ =_____V and the rms output current $I_{O(rms)}$ =_____A of the rectifier.

5. Substituting the measured $V_{P(max)}$ of Step 3 in Eq. (3-2-1), calculate $V_{O(av)}$=_____V. Is there good agreement between the calculated $V_{O(av)}$ and the measured $V_{O(av)}$ of Step 4?_____. Substituting the measured $V_{P(max)}$ of Step 3 into Eq. (3-2-3), calculate $V_{O(rms)}$ =_____V. Is there good agreement between the calculated $V_{O(rms)}$ and the measured $V_{O(rms)}$ of Step 4? _______. Are the values of $V_{O(rms)}$ and $V_{O(av)}$ nearly equal to each other? _______

6. Substituting the measured values of Step 4 and load resistor R=200Ω into Eqs. (3-2-4) and (3-2-5), calculate $P_{O(av)}$ =_____W and $P_{O(rms)}$ =_____W. Substituting the calculated results into Eq. (3-2-6), calculate η_r=_____%. Is this value very close to 99.83%? ______

7. Place the AC+DC/AC(SW2) and RMS/AV(SW1) selector switches of RMS Meter in AC and RMS positions, respectively. Measure the rms ripple voltage $V_{r(rms)}$=_____V. Substitute the measured results of Steps 4 and 7 into Eq. (3-2-7) and calculate $\lambda = \frac{V_{r(rms)}}{V_{o(av)}}$ = _____%. Is this value very close to 4%? _______

8. Modify the connections of Figure 3-2-2 to measure the phase voltage V_A (CH1) and the line current of phase A (CH2, identical to phase current) via Current Transducer as shown in Figure 3-2-4. Does the input current have dc component? __________

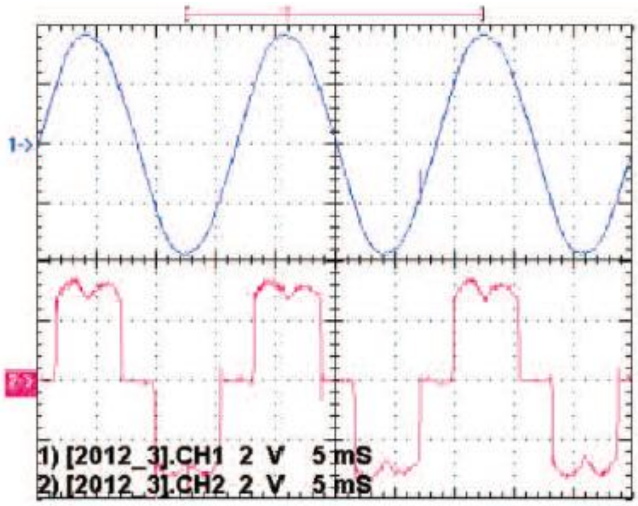


Figure 3-2-4 Measured phase voltage V_A (CH1) and input current (CH2) waveforms of three-phase full-wave diode rectifier with purely resistive load

9. Recover the load inductor by removing the connecting wire from inductor terminals. This modifies the purely resistive load to an inductive load. Repeat Step 8 to measure the ac input voltage and current waveforms of the rectifier, and record the results in Figure 3-2-5. Comparing with the result of Figure 3-2-4, does the rectifier with inductive load have more continuous load current than the rectifier with purely resistive load? __________

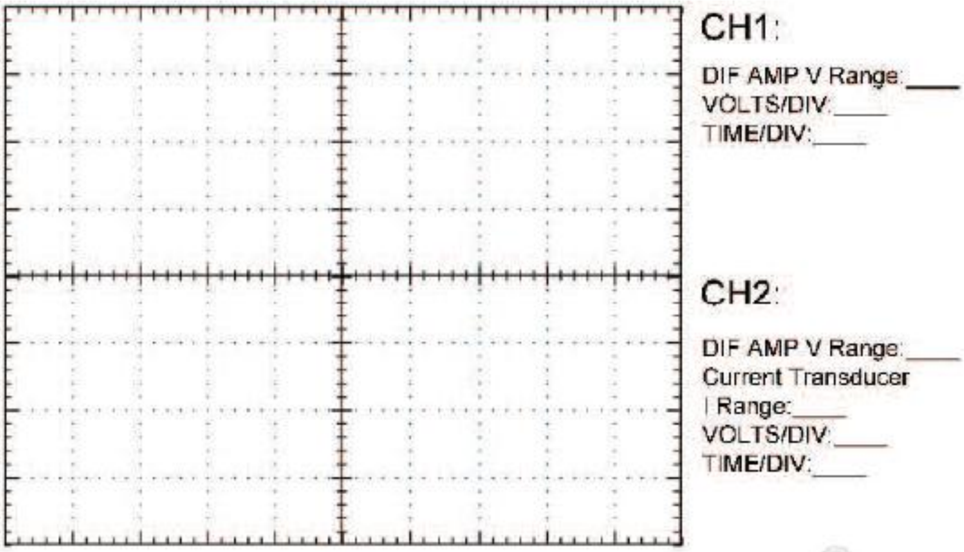


Figure 3-2-5 Measured phase voltage V_A (CH1) and input current (CH2) waveforms of three-phase full-wave diode rectifier with inductive load

10. Remain the load circuit in Step 9 unchanged. Modify the connections of Figure 3-2-2 to measure the phase voltage V_A (CH1) and the load current (CH2) via Current Transducer, and record the results in Figure 3-2-6. Does the output current waveform have smaller ripple factor? _____

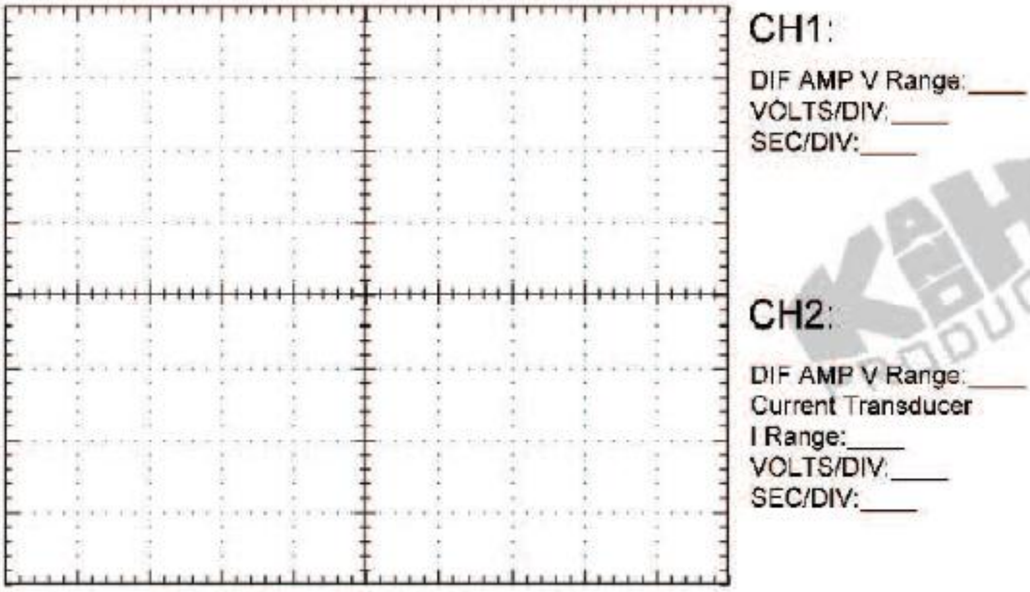


Figure 3-2-6 Measured phase voltage V_A (CH1) and load current (CH2) waveforms of three-phase full-wave diode rectifier with inductive load

Part 2. Three-Phase Full Wave Full Controlled Rectifier

Three Phase full wave full controlled rectifier is similar to three phase full wave diode rectifier. The only difference between the two is the six power diodes in three phase full wave diode rectifier are replaced by power thyristors.

With this lab you will understand the characteristics of three phase full wave full controlled rectifier, measure the voltage and current values.

BEFORE COME TO THIS LAB, YOU SHOULD

* Read the technical background on the report.
* Make some research on Three Phase Full Wave Full Controlled Rectifier.

AFTER COMPLETING THIS LAB, YOU SHOULD

* Know the circuit of Three Phase Full Wave Full Controlled Rectifier.
* Know the waveforms of Three Phase Full Wave Full Controlled Rectifier.

REQUIREMENTS

* Isolating Transformer * Differential Amplifier * Resistor Load Unit * Inductive Load Unit * Oscilloscope * Wires	* Thyristor Set * DC Power Supply * Reference Variable Generator * 3Q Phase Angle Controller * Current Transducer * Fuse Set

Experiment 3-5
Three-Phase Full-Wave Full-Controlled Rectifier

OBJECTIVE

1. To understand the characteristics and operating principle of three-phase full-wave full-controlled rectifier.
2. To compare the advantages and disadvantages between three-phase full-wave semi-controlled rectifier and three-phase full-wave full-controlled rectifier.
3. To measure the voltage and current values of three-phase full-wave full-controlled rectifier with various triggering angles.
4. To verify the characteristics of three-phase full-wave full-controlled rectifier.

DISCUSSION

The circuit construction of three-phase full-wave full-controlled rectifier is similar to that of three-phase full-wave diode rectifier. The only difference between the two is the six power diodes in three-phase full-wave diode rectifier are replaced by power thyristors. By varying the triggering angles of thyristors, the average output voltage of a three-phase rectifier can be varied. Compared with the single-phase full-wave controlled rectifier, three-phase full-wave full-controlled rectifier can provide smoother dc voltage and deliver higher power to the load. Compared with the three-phase full-wave semi-controlled rectifier, the three-phase full-wave full-controlled rectifier has smaller ripple component on output voltage (close to pure dc) and the polarity of output voltage is changeable; that is a two-quadrant converter

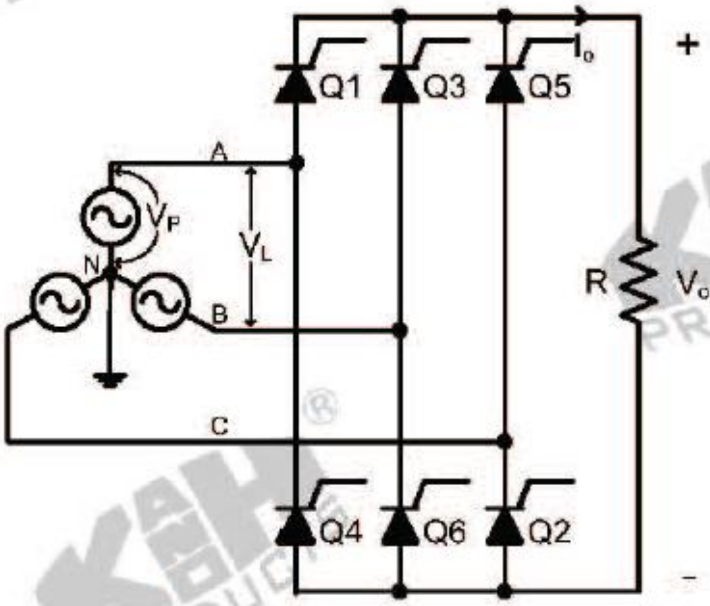
Figure 3-5-1 illustrates the circuit and waveforms of three-phase full-wave full-controlled rectifier with a purely resistive load. This figure shows the three-phase source voltages in positive phase sequence; that is, V_B lags V_A by 120°, V_C leads V_A by 120°.

Similar to the three-phase full-wave semi-controlled rectifier, the triggering signal of thyristors in three-phase full-wave full-controlled rectifier must be continuous pulse.

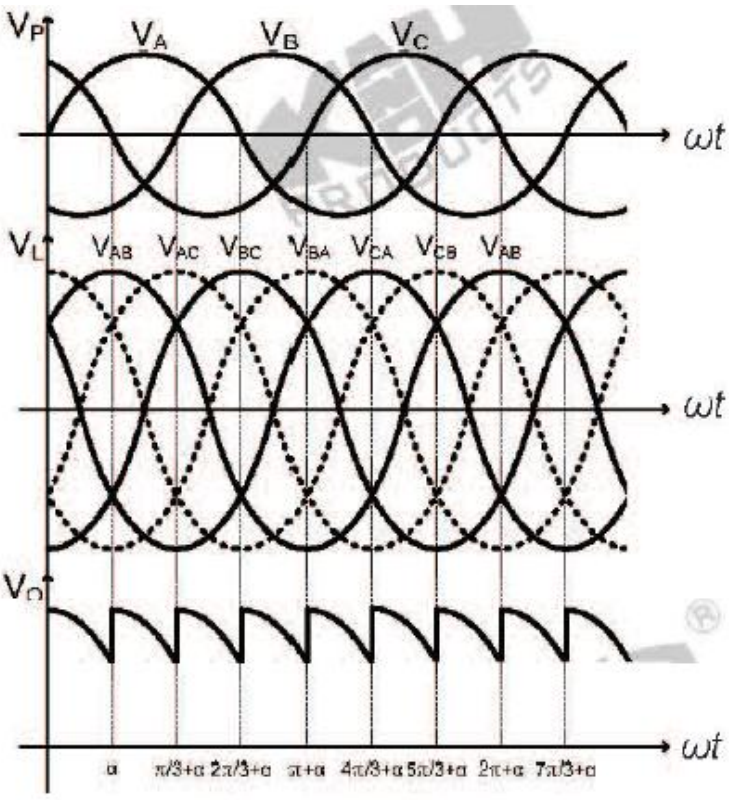
When the triggering angle α of thyristors is equal to or less than π/6, this circuit performs the same function as the three-phase full-wave diode rectifier does; that is, the average output voltage can not be varied. In normal operation, the triggering angle α of thyristors of this rectifier must be an angle between 30° and 180°. Moreover, since the three-phase full-wave full-controlled rectifier has six thyristors and two thyristors will conduct at a time, therefore the triggering signal of each thyristor must extend to π/3 (to overlay any two triggering signal by π/3); otherwise, only one thyristor can conduct at any instant so that no load current is generated.

As shown in Figure 3-5-1, during the interval $\alpha \leq \omega t \leq \pi/3+\alpha$, the voltage V_{AB} is maximum, thyristors Q1 and Q6 are triggered to conduct, so the rectified output voltage $V_O=V_{AB}$. During the interval $\pi/3+\alpha \leq \omega t \leq 2\pi/3+\alpha$, the voltage V_{AC} is maximum, thyristors Q1 and Q2 are triggered to conduct, whereas the thyristor Q6 is reverse-biased and turned off, so the rectified output voltage $V_O=V_{AC}$. During the $2\pi/3+\alpha \leq \omega t \leq \pi+\alpha$ interval, the voltage V_{BC} is maximum, thyristors Q2 and Q3 are triggered to conduct, whereas the thyristor Q1 is reverse-biased and turned off, so the output voltage $V_O=V_{BC}$ and so on.

As discussion above, the conduction angle of every thyristor is 60°. From the waveforms shown in Figure 3-5-1(b), we see that the ripple frequency of the three-phase full-wave full-controlled rectifier is 6 times the ac source frequency.



(a)



(b)

Figure 3-5-1 Circuit and waveforms of three-phase full-wave full-controlled rectifier with purely resistive load

By the definitions of symbols and abbreviations as previous experiments and the waveforms in Figure 3-5-1(b), the average value and rms value of output voltage are expressed as:

$$V_{O(av)} = \frac{1}{\frac{2\pi}{3}} \int_{\alpha}^{\frac{\pi}{3}+\alpha} \sqrt{3}V_{P(max)} \sin(\omega t + \tfrac{\pi}{6}) d(\omega t) \qquad (3\text{-}5\text{-}1)$$

$$V_{O(rms)} = \frac{1}{\frac{2\pi}{3}} \int_{\alpha}^{\frac{\pi}{3}+\alpha} \left[\sqrt{3}V_{P(max)} \sin(\omega t + \tfrac{\pi}{6})\right]^2 d(\omega t) \qquad (3\text{-}5\text{-}2)$$

In Eqs. (3-5-1) and (3-5-2), the integral waveform V_{AB} which leads V_A by $\pi/6$ (30°). When α=30°, $V_{O(av)}$ is equal to that of the three-phase full-wave diode rectifier. By varying various α values, $V_{O(av)}$ can be varied from $2.34V_{P(rms)}$ to $-2.34V_{P(rms)}$. That is, three-phase full-wave full-controlled rectifier is a two-quadrant converter and the polarity of average output voltage is changeable.

EQUIPMENT REQUIRED

1. PE-5340-3A Isolating Transformer x1
2. PE-5310-5B Fuse Set x1
3. PE-5310-5C Thyristor Set x3
4. PE-5310-2B Differential Amplifier x1
5. PE-5310-3C Resistor Load Unit x1
6. PE-5310-3E Inductive Load Unit x1
7. PE-5310-2C Current Transducer x1
8. PE-5310-1A DC Power Supply (±15V/2A) x1
9. PE-5310-2A Reference Variable Generator x1
10. PE-5310-2D 3ϕ Phase Angle Controller
11. Digital Storage Oscilloscope (DSO) x1
12. Connecting Wires and Bridging Plugs

PROCEDURE

1. Put modules PE-5310-5B, PE-5310-5C, PE-5310-2C, PE-5310-2B, PE-5310-1A, PE-5310-2A, and PE-5310-2D in Experimental Frame. Place DSO, PE-5310-3C and PE-5340-3A modules on workbench. Complete the connections by referring to the wiring diagram in Figure 3-5-2 using bridging plugs (curved lines) and connecting wires.

2. This rectifier operates from three-phase four-wire 220V (phase voltage = 127V) and the load circuit is a 100Ω resistor connected in series with a 200mH inductor. On Reference Variable Generator module, set the Vc Range selector switch to 0~+10V, and set the V control knob to 0%. On 3ϕ Phase Angle Controller module, select Pulse Train output, set α_{min}=30° and α_{max}=180°. Therefore the triggering angle can be varied between 30° and 180° by turning the V control knob of Reference Variable Generator.

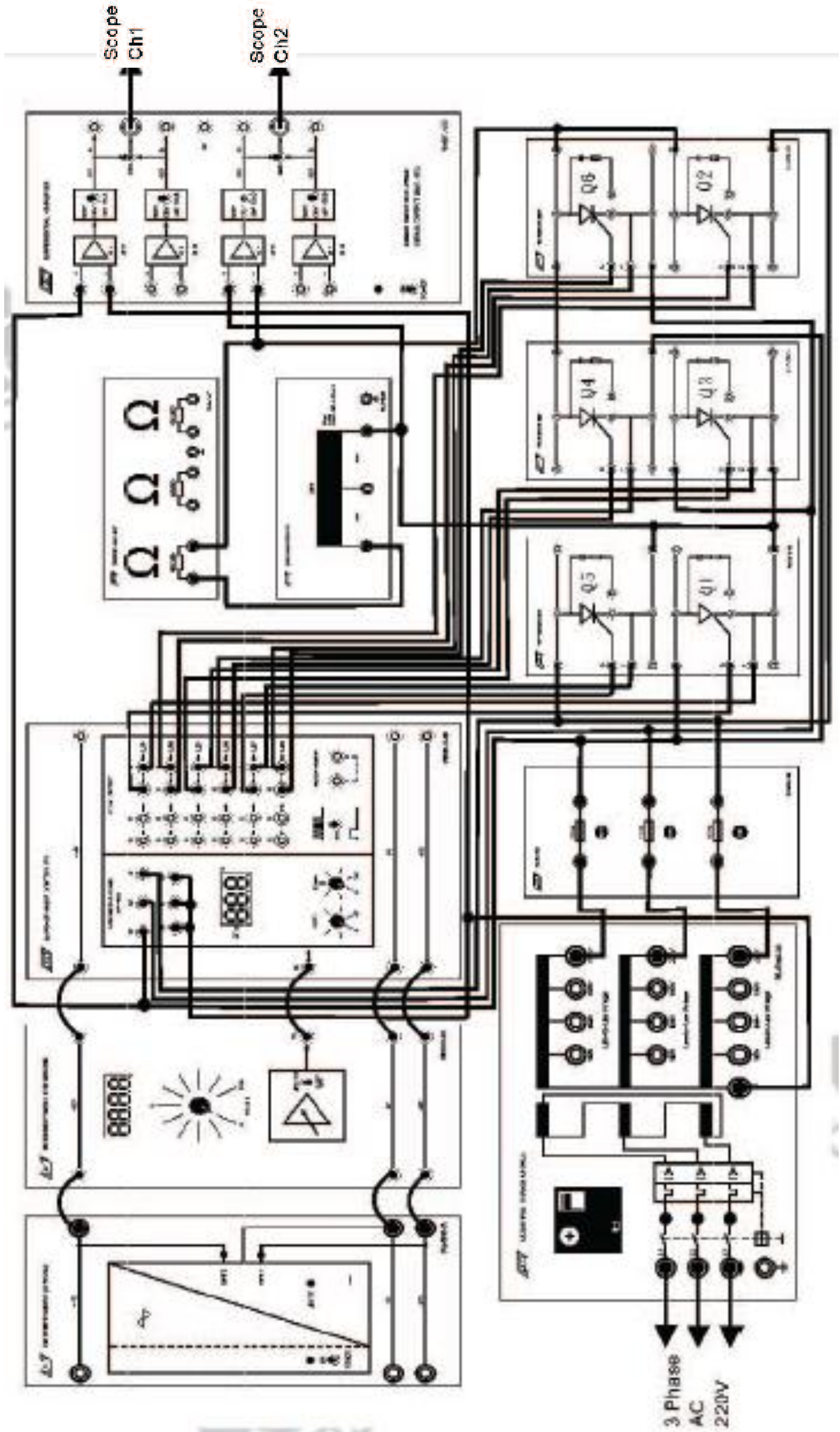


Figure 3-5-2 Wiring diagram for three-phase full-wave full-controlled rectifier

3. Short out the load inductor by placing a connecting wire directly across the inductor terminals. This forms a purely resistive load circuit. Set the V Range selector(SWA,SWC) switches of Differential Amplifiers Ch.A and Ch.C to 500V. Turn the V control knob of Reference Variable Generator to make α=60°. Using DSO, measure the phase voltage V_A (CH1) and load voltage (CH2) waveforms of the three-phase full-wave full-controlled rectifier as shown in Figure 3-5-3. Does the ripple frequency equal 6 times the frequency of input ac source?___________

4. Turn the V control knob of Reference Variable Generator to make α=90°. Using DSO, measure the phase voltage V_A (CH1) and the load voltage (CH2) waveforms of three-phase full-wave full-controlled rectifier as shown in Figure 3-5-4. Does the average output voltage decrease? ______.

   Note: With purely resistive load, the output current and output voltage are the same waveform.

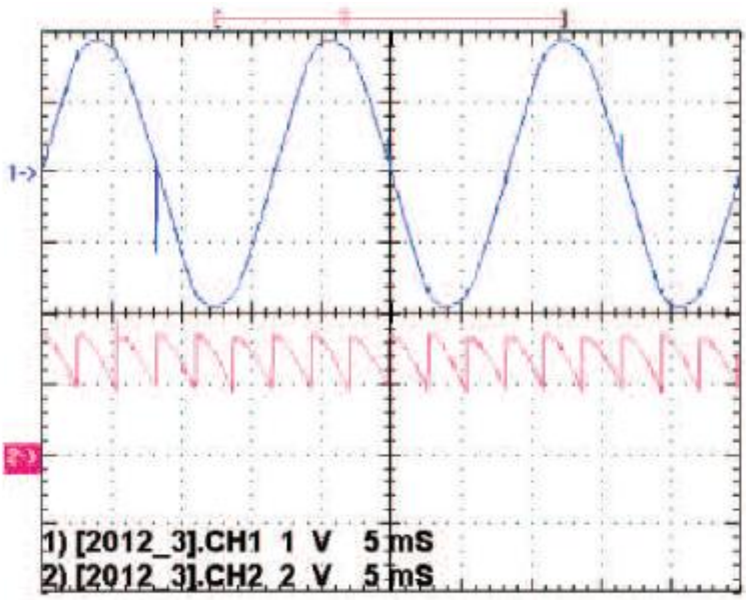


Figure 3-5-3 Measured phase voltage V_A (CH1) and load voltage (CH2) waveforms of three-phase full-wave full-controlled rectifier with purely resistive load (α=60°)

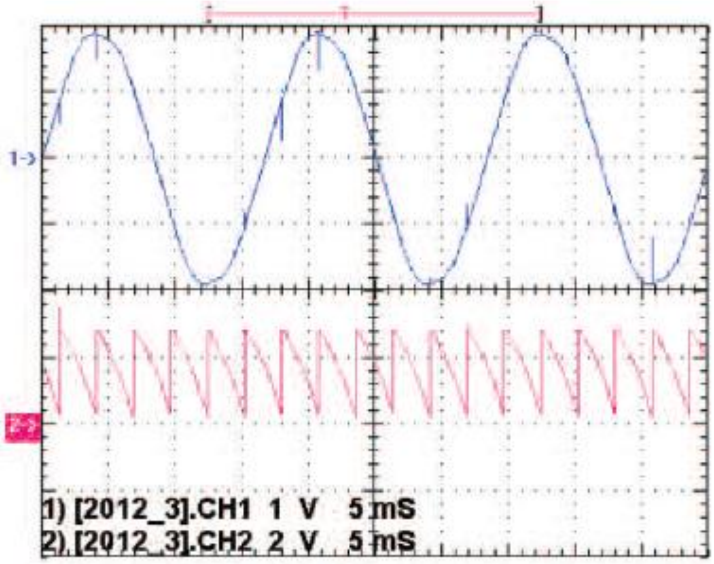
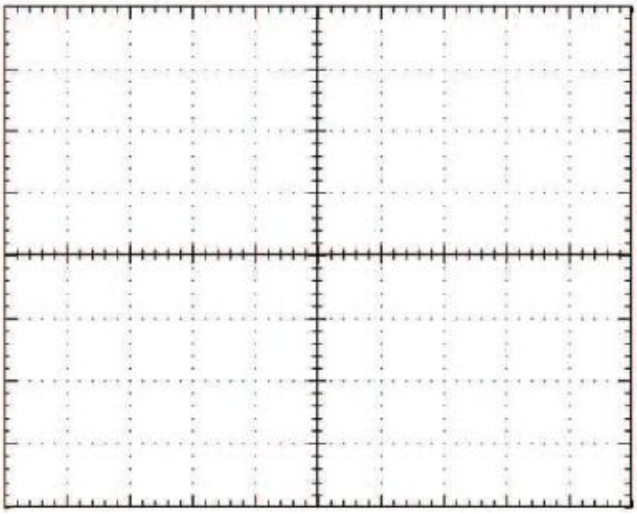


Figure 3-5-4 Measured phase voltage V_A (CH1) and load voltage (CH2) waveforms of three-phase full-wave full-controlled rectifier with purely resistive load (α=90°)

5. Recover the load inductor by removing the connecting wire from inductor terminals. This modifies the purely resistive load to an inductive load. Remain the settings of triggering angles in Step 4 unchanged. Modify the connections of Figure 3-5-2 to measure the phase voltage V_A (CH1) and the load current (CH2) via Current Transducer, and record the results in Figure 3-5-5. Comparing with the result of Figure 3-5-4, does the rectifier with inductive load have more continuous load current than the rectifier with purely resistive load? ________



CH1:
DIF AMP V Range:____
VOLTS/DIV:____
SEC/DIV:____

CH2:
DIF AMP V Range:____
Current Transducer
I Range:____
VOLTS/DIV:____
SEC/DIV:____

Figure 3-5-5 Measured phase voltage V_A (CH1) and load current (CH2) waveforms of three-phase full-wave full-controlled rectifier with inductive load (α=90°)

Laboratory Report:

- Laboratory Report must include, Your own oscilloscope figures for all required experiment steps.
- The main title will be “Experimental Waveforms”
- Clarify which figures belongs to which sections.
- The MS Word document that includes the figures will be printed and attached to this manual.