

# パワーエレクトロニクス 第八回 整流回路

平成31年6月5日

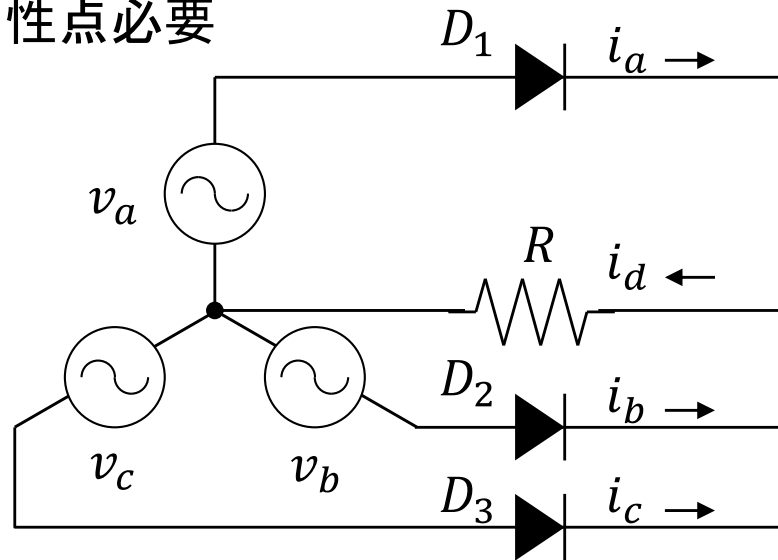
# 授業の予定

- パワーエレクトロニクスに必要な基礎知識
- パワー半導体デバイス
- 整流回路
- 他励式インバータ
- 交流電力制御とサイクロコンバータ
- 直流チョッパ
- DC-DCコンバータと共振形コンバータ
- 自励式インバータ
- 演習

# ダイオード整流回路

## 三相半波整流回路 抵抗負荷

中性点必要

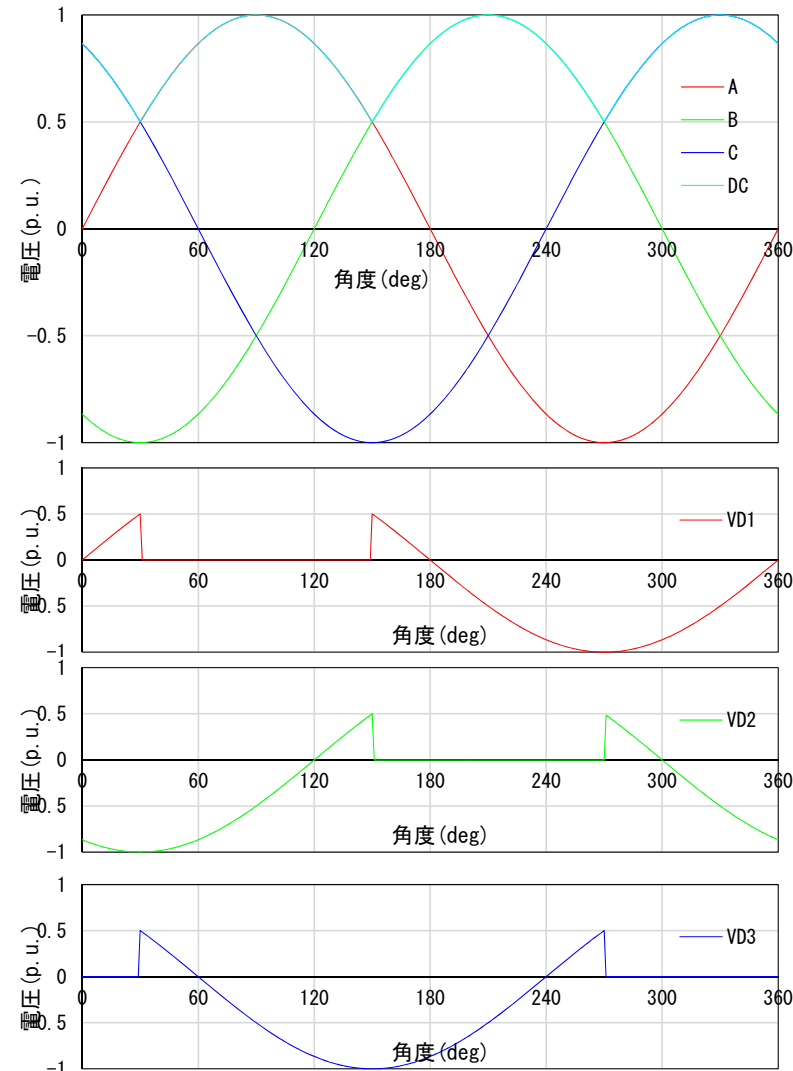


平衡三相交流電圧

$$v_a = V \sin \omega t$$

$$v_b = V \sin \left( \omega t - \frac{2}{3} \pi \right)$$

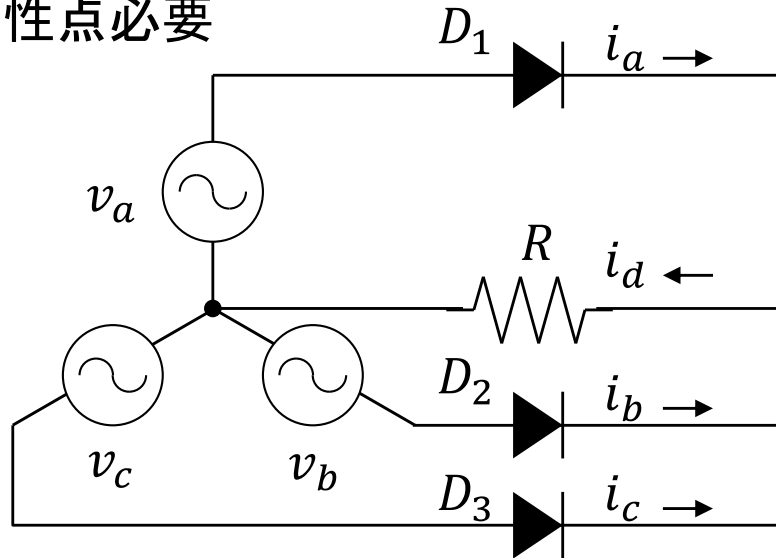
$$v_c = V \sin \left( \omega t + \frac{2}{3} \pi \right)$$



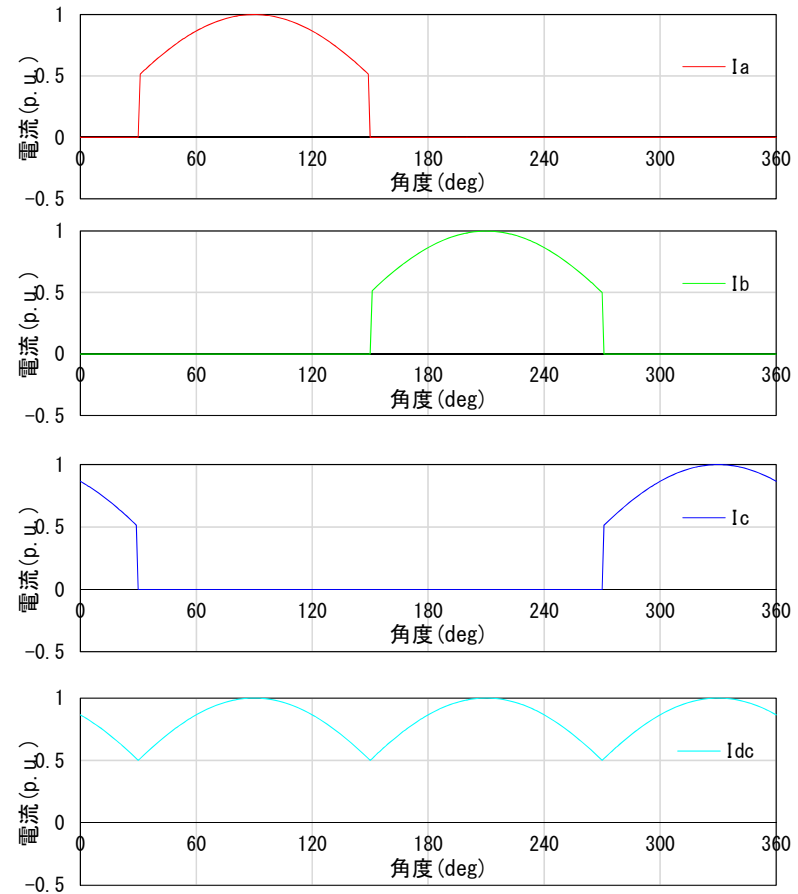
# ダイオード整流回路

## 三相半波整流回路 抵抗負荷

中性点必要



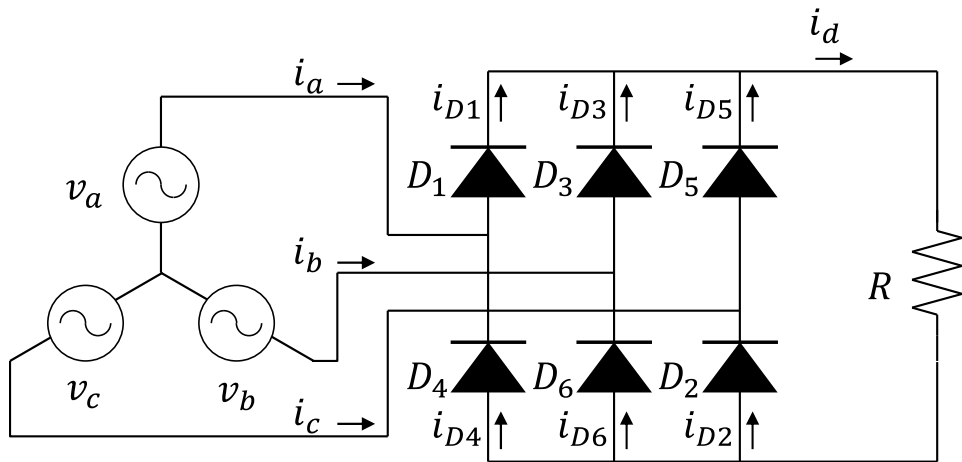
最も電圧の高い相のダイオードが導通する



電流

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

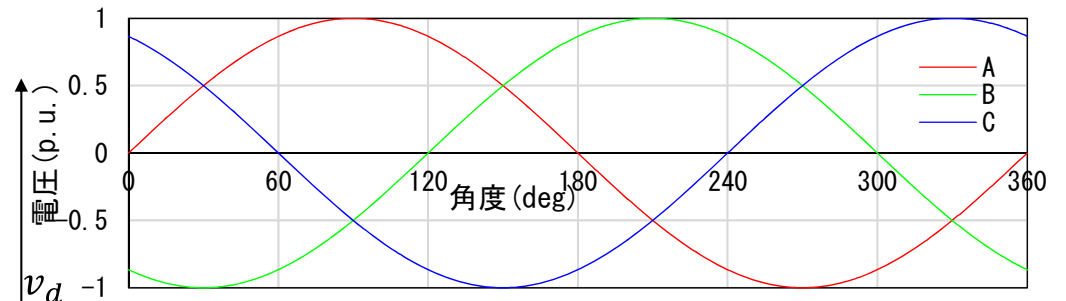


平衡三相交流電圧

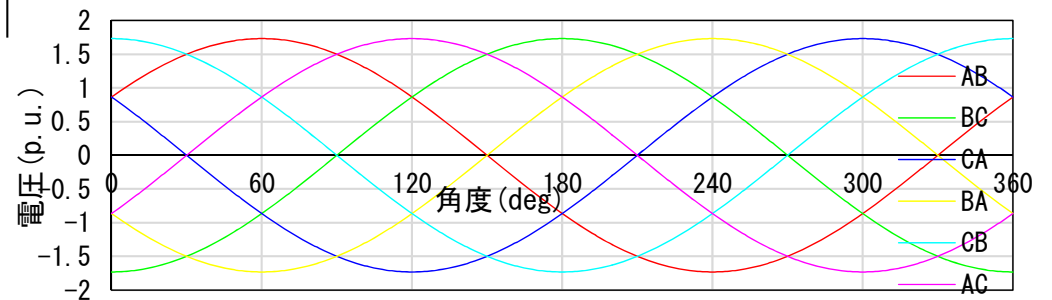
$$v_a = V \sin \omega t$$

$$v_b = V \sin \left( \omega t - \frac{2}{3} \pi \right)$$

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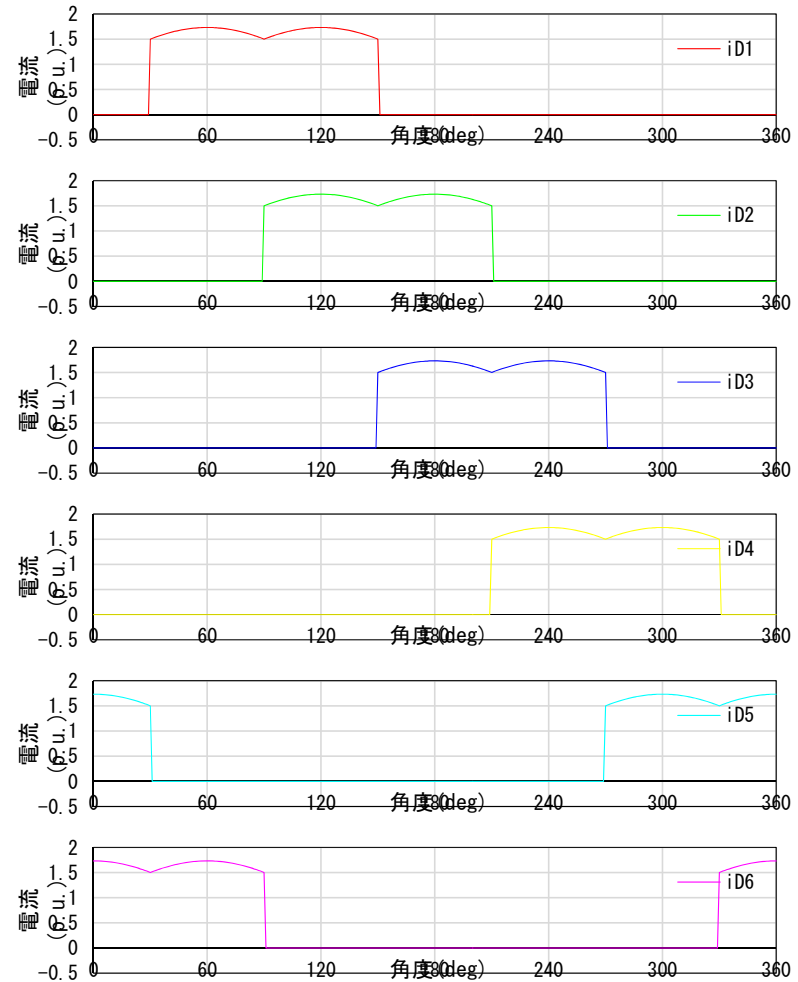
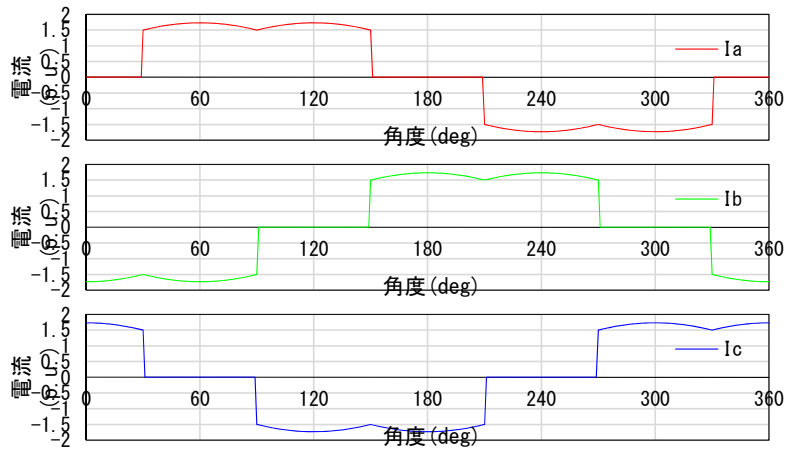
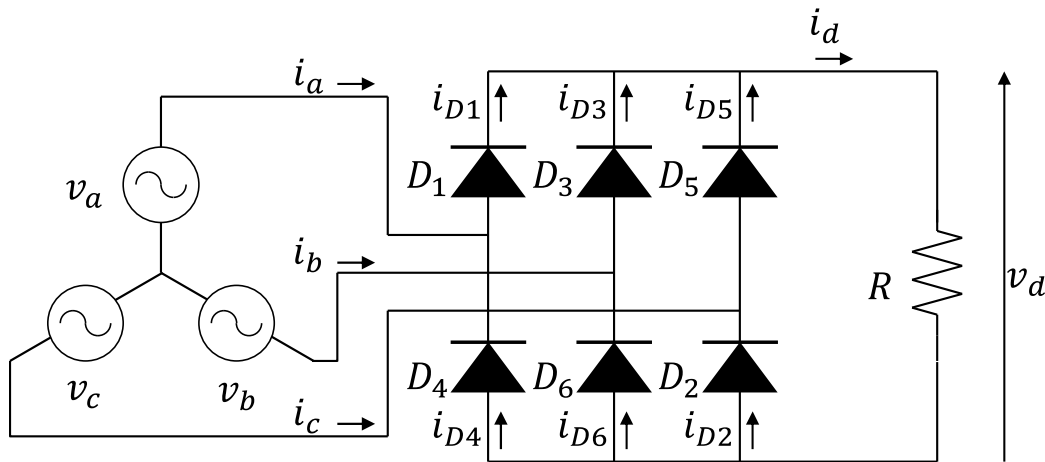
相電圧



線間電圧

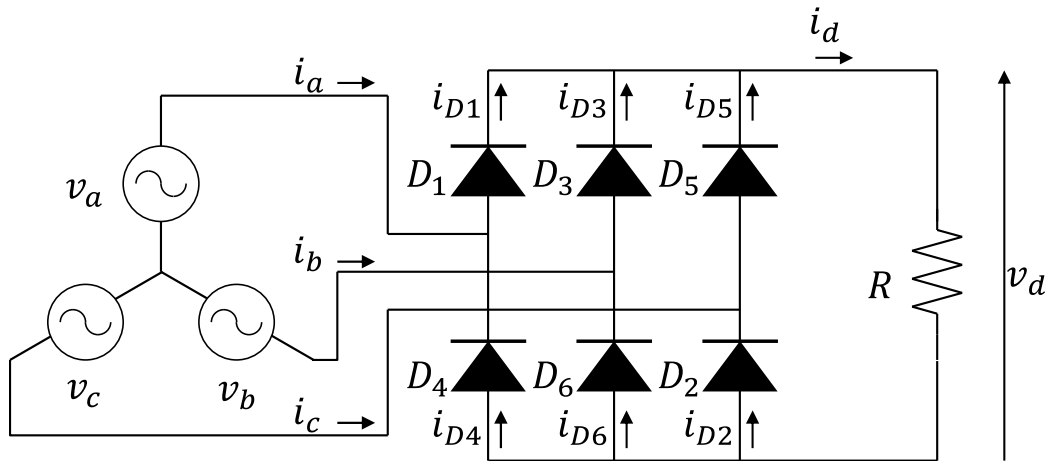
# ダイオード整流回路

## 三相全波整流回路 抵抗負荷



# ダイオード整流回路

## 三相全波整流回路 抵抗負荷



- 導通状態となるのは上下アーム共に一つずつ
- 最も相電圧の高い相の上アームが導通
- 最も相電圧の低い相の下アームが導通
- 同じ相の上下アームが同時に導通状態となることはない
- 負荷には線間電圧が出力

平衡三相交流電圧

$$v_a = V \sin \omega t$$

$$v_b = V \sin \left( \omega t - \frac{2}{3} \pi \right)$$

$$v_c = V \sin \left( \omega t + \frac{2}{3} \pi \right)$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- 相電圧と線間電圧の関係

- $$\begin{aligned} V_{ab} &= V \sin \omega t - V \sin \left( \omega t - \frac{2}{3} \pi \right) \\ &= V \left\{ \sin \omega t - \sin \omega t \cos \frac{2}{3} \pi + \cos \omega t \sin \frac{2}{3} \pi \right\} \\ &= V \left\{ \sin \omega t + \frac{1}{2} \sin \omega t + \frac{\sqrt{3}}{2} \cos \omega t \right\} \\ &= \sqrt{3} V \left\{ \frac{\sqrt{3}}{2} \sin \omega t + \frac{1}{2} \cos \omega t \right\} \\ &= \sqrt{3} V \left\{ \sin \omega t \cos \frac{\pi}{6} + \cos \omega t \sin \frac{\pi}{6} \right\} = \sqrt{3} V \sin \left( \omega t + \frac{\pi}{6} \right) \end{aligned}$$

- 線間電圧の大きさは相電圧の $\sqrt{3}$ 倍



# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- 線間電圧
  - $V_{ab} = \sqrt{3}V \sin\left(\omega t + \frac{\pi}{6}\right)$
  - $V_{bc} = \sqrt{3}V \sin\left(\omega t - \frac{\pi}{2}\right)$
  - $V_{ca} = \sqrt{3}V \sin\left(\omega t + \frac{5}{6}\pi\right)$
  - $V_{ba} = \sqrt{3}V \sin\left(\omega t - \frac{5}{6}\pi\right)$
  - $V_{cb} = \sqrt{3}V \sin\left(\omega t + \frac{\pi}{2}\right)$
  - $V_{ac} = \sqrt{3}V \sin\left(\omega t - \frac{\pi}{6}\right)$
- 線間電圧が最大値となる順序
  - ab → ac → bc → ba → ca → cb → ab
  - $V_{ab} = V_{cb}$ となる時点 $\left(\omega t < \frac{\pi}{6}\right)$ を基準にとる $\omega t' = 0$ 
    - $0 < \omega t' < \frac{\pi}{3}$  D1, D6
    - $\frac{\pi}{3} < \omega t' < \frac{2\pi}{3}$  D1, D2
    - $\frac{2\pi}{3} < \omega t' < \pi$  D2, D3
    - $\pi < \omega t' < \frac{4\pi}{3}$  D3, D4
    - $\frac{4\pi}{3} < \omega t' < \frac{5\pi}{3}$  D4, D5
    - $\frac{5\pi}{3} < \omega t' < 2\pi$  D5, D6

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- ダイオード別の導通期間
  - D1  $0 < \omega t' < \frac{2\pi}{3}$
  - D2  $\frac{\pi}{3} < \omega t' < \pi$
  - D3  $\frac{2\pi}{3} < \omega t' < \frac{4\pi}{3}$
  - D4  $\pi < \omega t' < \frac{5\pi}{3}$
  - D5  $\frac{4\pi}{3} < \omega t' < 2\pi$
  - D6  $\frac{5\pi}{3} < \omega t' < \frac{7\pi}{3}$
- 各導通期間は $\frac{2\pi}{3}$
- 相電流
  - $i_a = i_{D1} - i_{D4}$
  - $i_b = i_{D3} - i_{D6}$
  - $i_c = i_{D5} - i_{D2}$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- 直流出力平均電圧

$$\begin{aligned} \bullet \quad V_{Oavg} &= \frac{1}{\pi} \int_{\frac{\pi}{3}}^{\frac{\pi}{2}} \sqrt{3}V \sin\left(\omega t + \frac{\pi}{6}\right) d\omega t \\ &= \frac{3\sqrt{3}V}{\pi} \left[ -\cos\left(\omega t + \frac{\pi}{6}\right) \right]_{\frac{\pi}{6}}^{\frac{\pi}{2}} = \frac{3\sqrt{3}V}{\pi} \left[ -\cos\frac{2\pi}{3} + \cos\frac{\pi}{3} \right] = \frac{3\sqrt{3}V}{\pi} \end{aligned}$$

- 直流出力平均電流

$$\bullet \quad I_{Oavg} = \frac{V_O}{R}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- 直流出力電圧実効値

$$\begin{aligned}
 V_{Orms} &= \sqrt{\frac{1}{\frac{\pi}{3}} \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \left\{ \sqrt{3}V \sin\left(\omega t + \frac{\pi}{6}\right) \right\}^2 d\omega t} = \frac{3V}{\sqrt{\pi}} \sqrt{\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \sin^2\left(\omega t + \frac{\pi}{6}\right) d\omega t} \\
 &= \frac{3V}{\sqrt{\pi}} \sqrt{\int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{1 - \cos\left(2\omega t + \frac{\pi}{3}\right)}{2} d\omega t} = \frac{3V}{\sqrt{\pi}} \sqrt{\left[ \frac{\omega t}{2} - \frac{\sin\left(2\omega t + \frac{\pi}{3}\right)}{4} \right]_{\frac{\pi}{6}}^{\frac{\pi}{2}}} \\
 &= \frac{3V}{\sqrt{\pi}} \sqrt{\frac{\pi}{4} - \frac{\pi}{12} - \sin\frac{4\pi}{3} + \sin\frac{2\pi}{3}} = \frac{3V}{\sqrt{\pi}} \sqrt{\frac{\pi}{6} + \sqrt{3}}
 \end{aligned}$$

- 直流出力電流実効値

- $$I_{Orms} = \frac{V_{Orms}}{R} = \frac{3V}{R\sqrt{\pi}} \sqrt{\frac{\pi}{6} + \sqrt{3}}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- ダイオード一つ当たり導通期間1/3周期

- 平均電流  $I_{Davg} = \frac{1}{3} I_{Oavg}$

- 実効値電流  $I_{Drms} = \sqrt{\frac{1}{3} I_{Orms}^2} = \frac{1}{\sqrt{3}} I_{Orms}$

- 相電流

- 実効値電流  $I_{prms} = \sqrt{\frac{2}{3} I_{Orms}^2} = \sqrt{\frac{2}{3}} I_{Orms}$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- 出力電圧高調波

- $$v_d(t) = \sum_{i=0}^{\infty} [a_i \cos i\omega t + b_i \sin i\omega t]$$

- $$a_0 = V_{Oavg} = \frac{3\sqrt{3}V}{\pi} \quad \text{直流成分}$$

- $$b_0 = 0$$

- $$a_i = \frac{\sqrt{3}V}{2\pi} \left\{ \begin{aligned} & \int_{\frac{\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t + \frac{\pi}{6}\right) \cos i\omega t \, d\omega t + \int_{\frac{5\pi}{6}}^{\frac{7\pi}{6}} \sin\left(\omega t - \frac{\pi}{6}\right) \cos i\omega t \, d\omega t \\ & + \int_{\frac{5\pi}{6}}^{\frac{7\pi}{6}} \sin\left(\omega t - \frac{\pi}{2}\right) \cos i\omega t \, d\omega t + \int_{\frac{3\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t - \frac{5\pi}{6}\right) \cos i\omega t \, d\omega t \\ & + \int_{\frac{3\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t + \frac{5\pi}{6}\right) \cos i\omega t \, d\omega t + \int_{\frac{11\pi}{6}}^{\frac{13\pi}{6}} \sin\left(\omega t + \frac{\pi}{2}\right) \cos i\omega t \, d\omega t \end{aligned} \right\}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $a_i$ の係数

- $$\int_{\frac{\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t + \frac{\pi}{6}\right) \cos i\omega t d\omega t = \int_{\frac{\pi}{6}}^{\frac{2\pi}{6}} \frac{\sin\left((1+i)\omega t + \frac{\pi}{6}\right) - \sin\left((1-i)\omega t + \frac{\pi}{6}\right)}{2} d\omega t$$

- $$= \left[ \frac{\cos\left((1-i)\omega t + \frac{\pi}{6}\right)}{2(1-i)} - \frac{\cos\left((1+i)\omega t + \frac{\pi}{6}\right)}{2(1+i)} \right]_{\frac{\pi}{6}}^{\frac{2\pi}{6}}$$

- $$= \frac{\cos\left((1-i)\frac{\pi}{2} + \frac{\pi}{6}\right) - \cos\left((1-i)\frac{\pi}{6} + \frac{\pi}{6}\right)}{2(1-i)} - \frac{\cos\left((1+i)\frac{\pi}{2} + \frac{\pi}{6}\right) - \cos\left((1+i)\frac{\pi}{6} + \frac{\pi}{6}\right)}{2(1+i)}$$

- $$= \frac{\cos\left(-\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \cos\left(-\frac{\pi}{6}i + \frac{\pi}{3}\right)}{2(1-i)} - \frac{\cos\left(\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \cos\left(\frac{\pi}{6}i + \frac{\pi}{3}\right)}{2(1+i)}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $$\begin{aligned} & \cos\left(-\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \cos\left(-\frac{\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(-\frac{5\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(-\frac{\pi}{2}i + \frac{\pi}{3}\right) \\ & + \cos\left(-\frac{7\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(-\frac{5\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(-\frac{3\pi}{2}i + \frac{2\pi}{3}\right) - \\ & \cos\left(-\frac{7\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(-\frac{11\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(-\frac{3\pi}{2}i + \frac{\pi}{3}\right) + \cos\left(-\frac{13\pi}{6}i + \frac{2\pi}{3}\right) \\ & - \cos\left(-\frac{11\pi}{6}i + \frac{\pi}{3}\right) \end{aligned}$$
- $$\begin{aligned} & = -\cos -\frac{\pi}{6}i - \cos -\frac{\pi}{2}i - \cos -\frac{5\pi}{6}i - \cos -\frac{7\pi}{6}i - \cos -\frac{3\pi}{2}i - \\ & \cos -\frac{11\pi}{6}i \end{aligned}$$
- $$\begin{aligned} & = -\left\{ \cos\frac{\pi}{6}i + \cos\frac{\pi}{2}i + \cos\frac{5\pi}{6}i + \cos\frac{7\pi}{6}i + \cos\frac{3\pi}{2}i + \cos\frac{11\pi}{6}i \right\} \\ & \quad \bullet \cos\left(A + \frac{2\pi}{3}\right) - \cos\left(A + \frac{\pi}{3}\right) = \cos A \cos\frac{2\pi}{3} - \sin A \sin\frac{2\pi}{3} - \\ & \quad \cos A \cos\frac{\pi}{3} + \sin A \sin\frac{\pi}{3} = -\cos A \end{aligned}$$



# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $$\cos\left(\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \cos\left(\frac{\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(\frac{5\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(\frac{\pi}{2}i + \frac{\pi}{3}\right) + \cos\left(\frac{7\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(\frac{5\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(\frac{3\pi}{2}i + \frac{2\pi}{3}\right) - \cos\left(\frac{7\pi}{6}i + \frac{\pi}{3}\right) + \cos\left(\frac{11\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(\frac{3\pi}{2}i + \frac{\pi}{3}\right) + \cos\left(\frac{13\pi}{6}i + \frac{2\pi}{3}\right) - \cos\left(\frac{11\pi}{6}i + \frac{\pi}{3}\right)$$
- $$= -\cos\frac{\pi}{6}i - \cos\frac{\pi}{2}i - \cos\frac{5\pi}{6}i - \cos\frac{7\pi}{6}i - \cos\frac{3\pi}{2}i - \cos\frac{11\pi}{6}i$$
- $$= -\left\{\cos\frac{\pi}{6}i + \cos\frac{\pi}{2}i + \cos\frac{5\pi}{6}i + \cos\frac{7\pi}{6}i + \cos\frac{3\pi}{2}i + \cos\frac{11\pi}{6}i\right\}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $i = 6k$ 
  - $\cos \frac{\pi}{6} 6k + \cos \frac{\pi}{2} 6k + \cos \frac{5\pi}{6} 6k + \cos \frac{7\pi}{6} 6k + \cos \frac{3\pi}{2} 6k + \cos \frac{11\pi}{6} 6k = 6 \cos \pi k = 6(-1)^k$
- $i = 6k + 1$ 
  - $\cos \frac{\pi}{6} (6k + 1) + \cos \frac{\pi}{2} (6k + 1) + \cos \frac{5\pi}{6} (6k + 1) + \cos \frac{7\pi}{6} (6k + 1) + \cos \frac{3\pi}{2} (6k + 1) + \cos \frac{11\pi}{6} (6k + 1) = 0$
- $i = 6k + 2$ 
  - $\cos \frac{\pi}{6} (6k + 2) + \cos \frac{\pi}{2} (6k + 2) + \cos \frac{5\pi}{6} (6k + 2) + \cos \frac{7\pi}{6} (6k + 2) + \cos \frac{3\pi}{2} (6k + 2) + \cos \frac{11\pi}{6} (6k + 2) = 0$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $i = 6k + 3$ 
  - $\cos \frac{\pi}{6}(6k + 3) + \cos \frac{\pi}{2}(6k + 3) + \cos \frac{5\pi}{6}(6k + 3) + \cos \frac{7\pi}{6}(6k + 3) + \cos \frac{3\pi}{2}(6k + 3) + \cos \frac{11\pi}{6}(6k + 3) = 0$
- $i = 6k + 4$ 
  - $\cos \frac{\pi}{6}(6k + 4) + \cos \frac{\pi}{2}(6k + 1) + \cos \frac{5\pi}{6}(6k + 4) + \cos \frac{7\pi}{6}(6k + 4) + \cos \frac{3\pi}{2}(6k + 4) + \cos \frac{11\pi}{6}(6k + 4) = 0$
- $i = 6k + 5$ 
  - $\cos \frac{\pi}{6}(6k + 5) + \cos \frac{\pi}{2}(6k + 5) + \cos \frac{5\pi}{6}(6k + 5) + \cos \frac{7\pi}{6}(6k + 5) + \cos \frac{3\pi}{2}(6k + 5) + \cos \frac{11\pi}{6}(6k + 5) = 0$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $a_i = \frac{\sqrt{3}V}{2\pi} \left\{ \frac{-6(-1)^k}{2(1-i)} - \frac{6(-1)^k}{2(1+i)} \right\} = -\frac{3\sqrt{3}V}{2\pi} (-1)^k$
- $i = 6k$  (6の整数倍の成分のみ)

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $$b_i = \frac{\sqrt{3}V}{2\pi} \left\{ \begin{aligned} & \int_{\frac{\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t + \frac{\pi}{6}\right) \sin i\omega t d\omega t + \int_{\frac{5\pi}{6}}^{\frac{7\pi}{6}} \sin\left(\omega t - \frac{\pi}{6}\right) \sin i\omega t d\omega t \\ & + \int_{\frac{5\pi}{6}}^{\frac{7\pi}{6}} \sin\left(\omega t - \frac{\pi}{2}\right) \sin i\omega t d\omega t + \int_{\frac{3\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t - \frac{5\pi}{6}\right) \sin i\omega t d\omega t \\ & + \int_{\frac{3\pi}{6}}^{\frac{2\pi}{6}} \sin\left(\omega t + \frac{5\pi}{6}\right) \sin i\omega t d\omega t + \int_{\frac{11\pi}{6}}^{\frac{13\pi}{6}} \sin\left(\omega t + \frac{\pi}{2}\right) \sin i\omega t d\omega t \end{aligned} \right\}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

$b_i$ の係数

$$\begin{aligned}
 \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \sin\left(\omega t + \frac{\pi}{6}\right) \sin i\omega t \, d\omega t &= \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \frac{\cos\left((1-i)\omega t + \frac{\pi}{6}\right) + \cos\left((1+i)\omega t + \frac{\pi}{6}\right)}{2} \, d\omega t \\
 &= \left[ \frac{\sin\left((1-i)\omega t + \frac{\pi}{6}\right)}{2(1-i)} + \frac{\sin\left((1+i)\omega t + \frac{\pi}{6}\right)}{2(1+i)} \right]_{\frac{\pi}{6}}^{\frac{\pi}{2}} \\
 &= \frac{\sin\left((1-i)\frac{\pi}{2} + \frac{\pi}{6}\right) - \sin\left((1-i)\frac{\pi}{6} + \frac{\pi}{6}\right)}{2(1-i)} \\
 &\quad + \frac{\sin\left((1+i)\frac{\pi}{2} + \frac{\pi}{6}\right) - \sin\left((1+i)\frac{\pi}{6} + \frac{\pi}{6}\right)}{2(1+i)} \\
 &= \frac{\sin\left(-\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{\pi}{6}i + \frac{\pi}{3}\right)}{2(1-i)} + \frac{\sin\left(\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(\frac{\pi}{6}i + \frac{\pi}{3}\right)}{2(1+i)}
 \end{aligned}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

$$\begin{aligned}
 & \sin\left(-\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{\pi}{6}i + \frac{\pi}{3}\right) + \sin\left(-\frac{5\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{\pi}{2}i + \frac{\pi}{3}\right) \\
 & + \sin\left(-\frac{7\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{5\pi}{6}i + \frac{\pi}{3}\right) + \sin\left(-\frac{3\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{7\pi}{6}i + \frac{\pi}{3}\right) \\
 & + \sin\left(-\frac{11\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(-\frac{3\pi}{2}i + \frac{\pi}{3}\right) + \sin\left(-\frac{13\pi}{6}i + \frac{2\pi}{3}\right) \\
 & - \sin\left(-\frac{11\pi}{6}i + \frac{\pi}{3}\right) \\
 & = \sin -\frac{\pi}{6}i + \sin -\frac{\pi}{2}i + \sin -\frac{5\pi}{6}i + \sin -\frac{7\pi}{6}i + \sin -\frac{3\pi}{2}i + \sin -\frac{11\pi}{6}i \\
 & = -\left\{ \sin \frac{\pi}{6}i + \sin \frac{\pi}{2}i + \sin \frac{5\pi}{6}i + \sin \frac{7\pi}{6}i + \sin \frac{3\pi}{2}i + \sin \frac{11\pi}{6}i \right\} \\
 & \bullet \sin\left(A + \frac{2\pi}{3}\right) - \sin\left(A + \frac{\pi}{3}\right) = \sin A \cos \frac{2\pi}{3} + \cos A \sin \frac{2\pi}{3} - \\
 & \sin A \cos \frac{\pi}{3} - \cos A \sin \frac{\pi}{3} = \sin A
 \end{aligned}$$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $$\begin{aligned} & \sin\left(\frac{\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(\frac{\pi}{6}i + \frac{\pi}{3}\right) + \sin\left(\frac{5\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(\frac{\pi}{2}i + \frac{\pi}{3}\right) + \\ & \sin\left(\frac{7\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(\frac{5\pi}{6}i + \frac{\pi}{3}\right) + \sin\left(\frac{3\pi}{2}i + \frac{2\pi}{3}\right) - \sin\left(\frac{7\pi}{6}i + \frac{\pi}{3}\right) + \\ & \sin\left(\frac{11\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(\frac{3\pi}{2}i + \frac{\pi}{3}\right) + \sin\left(\frac{13\pi}{6}i + \frac{2\pi}{3}\right) - \sin\left(\frac{11\pi}{6}i + \frac{\pi}{3}\right) \end{aligned}$$
- $$= \sin\frac{\pi}{6}i + \sin\frac{\pi}{2}i + \sin\frac{5\pi}{6}i + \sin\frac{7\pi}{6}i + \sin\frac{3\pi}{2}i + \sin\frac{11\pi}{6}i$$



# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $i = 6k$ 
  - $\sin \frac{\pi}{6} 6k + \sin \frac{\pi}{2} 6k + \sin \frac{5\pi}{6} 6k + \sin \frac{7\pi}{6} 6k + \sin \frac{3\pi}{2} 6k + \sin \frac{11\pi}{6} 6k = 0$
- $i = 6k + 1$ 
  - $\sin \frac{\pi}{6} (6k + 1) + \sin \frac{\pi}{2} (6k + 1) + \sin \frac{5\pi}{6} (6k + 1) + \sin \frac{7\pi}{6} (6k + 1) + \sin \frac{3\pi}{2} (6k + 1) + \sin \frac{11\pi}{6} (6k + 1) = 0$
- $i = 6k + 2$ 
  - $\sin \frac{\pi}{6} (6k + 2) + \sin \frac{\pi}{2} (6k + 2) + \sin \frac{5\pi}{6} (6k + 2) + \sin \frac{7\pi}{6} (6k + 2) + \sin \frac{3\pi}{2} (6k + 2) + \sin \frac{11\pi}{6} (6k + 2) = 0$

# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

- $i = 6k + 3$ 
  - $\sin \frac{\pi}{6}(6k + 3) + \sin \frac{\pi}{2}(6k + 3) + \sin \frac{5\pi}{6}(6k + 3) + \sin \frac{7\pi}{6}(6k + 3) + \sin \frac{3\pi}{2}(6k + 3) + \sin \frac{11\pi}{6}(6k + 3) = 0$
- $i = 6k + 4$ 
  - $\sin \frac{\pi}{6}(6k + 4) + \sin \frac{\pi}{2}(6k + 4) + \sin \frac{5\pi}{6}(6k + 4) + \sin \frac{7\pi}{6}(6k + 4) + \sin \frac{3\pi}{2}(6k + 4) + \sin \frac{11\pi}{6}(6k + 4) = 0$
- $i = 6k + 5$ 
  - $\sin \frac{\pi}{6}(6k + 5) + \sin \frac{\pi}{2}(6k + 5) + \sin \frac{5\pi}{6}(6k + 5) + \sin \frac{7\pi}{6}(6k + 5) + \sin \frac{3\pi}{2}(6k + 5) + \sin \frac{11\pi}{6}(6k + 5) = 0$

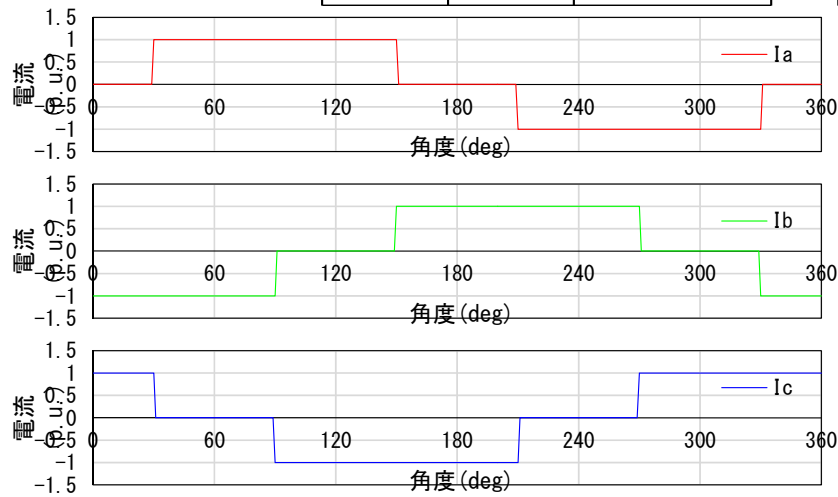
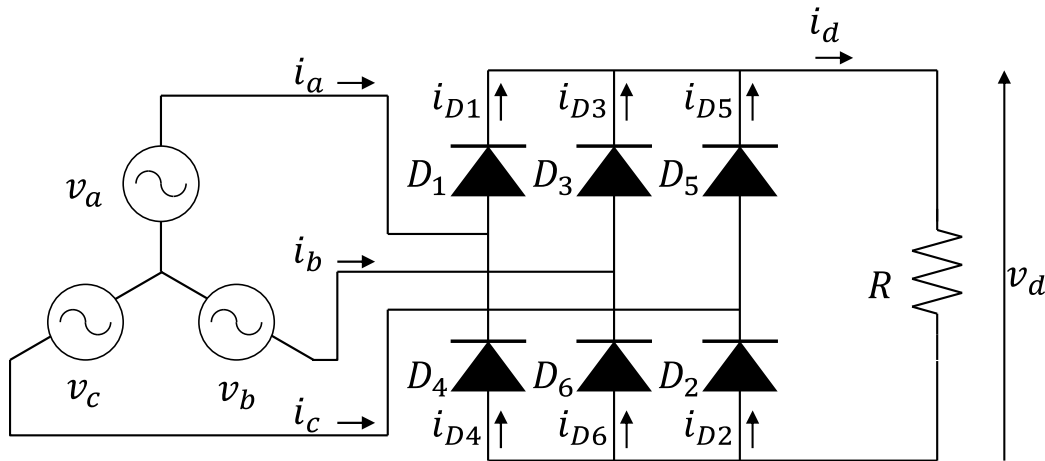
# ダイオード整流回路

## 三相全波整流回路 抵抗負荷

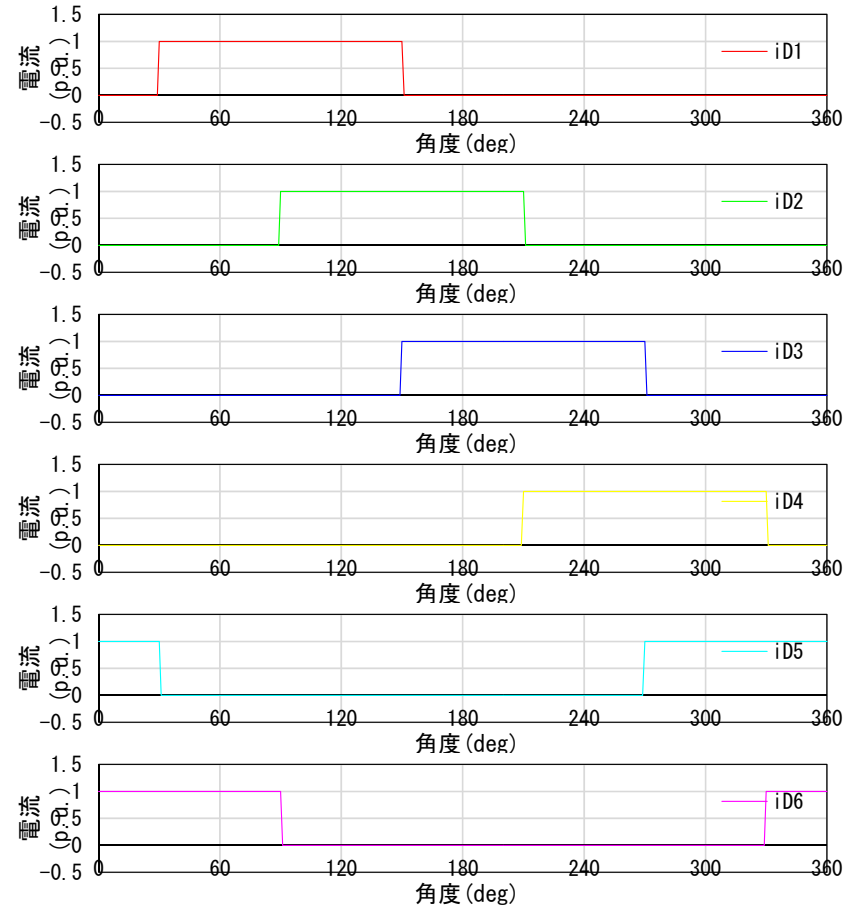
- $b_i = 0$

# ダイオード整流回路

## 三相全波整流回路 直流定電流



相電流



ダイオード電流

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- 交流相電流実効値

$$I_{prms} = \sqrt{\frac{1}{2\pi} \left\{ \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} I_o^2 d\omega t + \int_{\frac{7\pi}{6}}^{\frac{11\pi}{6}} (-I_o)^2 d\omega t \right\}} = \frac{I_o}{\sqrt{2\pi}} \sqrt{\left\{ \frac{5\pi}{6} - \frac{\pi}{6} + \frac{11\pi}{6} - \frac{7\pi}{6} \right\}}$$
$$= I_o \sqrt{\frac{2}{3}}$$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- 交流電流高調波

- $i_o(t) = \sum_{i=0}^{\infty} [a_i \cos i\omega t + b_i \sin i\omega t]$

- $a_0 = 0$

- $b_0 = 0$

直流成分

- $a_i = \frac{1}{2\pi} \left\{ \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} I_o \cos i\omega t d\omega t + \int_{\frac{7\pi}{6}}^{\frac{11\pi}{6}} -I_o \cos i\omega t d\omega t \right\}$

- $= \frac{I_o}{2\pi} \left\{ \left[ \frac{\sin i\omega t}{i} \right]_{\frac{\pi}{6}}^{\frac{5\pi}{6}} - \left[ \frac{\sin i\omega t}{i} \right]_{\frac{7\pi}{6}}^{\frac{11\pi}{6}} \right\}$

- $= \frac{I_o}{2\pi i} \left\{ \sin \frac{5\pi}{6} i - \sin \frac{\pi}{6} i - \sin \frac{11\pi}{6} i + \sin \frac{7\pi}{6} i \right\}$

- $= \frac{I_o}{2\pi i} \left\{ -\sin \frac{\pi}{6} i + \sin \frac{5\pi}{6} i + \sin \frac{7\pi}{6} i - \sin \frac{11\pi}{6} i \right\}$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

$$\begin{aligned} \bullet \quad b_i &= \frac{1}{2\pi} \left\{ \int_{\frac{\pi}{6}}^{\frac{5\pi}{6}} I_o \sin i\omega t \, d\omega t + \int_{\frac{7\pi}{6}}^{\frac{11\pi}{6}} -I_o \sin i\omega t \, d\omega t \right\} \\ \bullet \quad &= \frac{I_o}{2\pi} \left\{ \left[ \frac{-\cos i\omega t}{i} \right]_{\frac{\pi}{6}}^{\frac{5\pi}{6}} - \left[ \frac{-\cos i\omega t}{i} \right]_{\frac{7\pi}{6}}^{\frac{11\pi}{6}} \right\} \\ \bullet \quad &= \frac{I_o}{2\pi i} \left\{ -\cos \frac{5\pi}{6} i + \cos \frac{\pi}{6} i + \cos \frac{11\pi}{6} i - \cos \frac{7\pi}{6} i \right\} \\ \bullet \quad &= \frac{I_o}{2\pi i} \left\{ \cos \frac{\pi}{6} i - \cos \frac{5\pi}{6} i - \cos \frac{7\pi}{6} i + \cos \frac{11\pi}{6} i \right\} \end{aligned}$$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- $i = 6k$ 
  - $-\sin \frac{\pi}{6} 6k + \sin \frac{5\pi}{6} 6k + \sin \frac{7\pi}{6} 6k - \sin \frac{11\pi}{6} 6k = 0$
- $i = 6k + 1$ 
  - $-\sin \frac{\pi}{6} (6k + 1) + \sin \frac{5\pi}{6} (6k + 1) + \sin \frac{7\pi}{6} (6k + 1) - \sin \frac{11\pi}{6} (6k + 1) = 0$
- $i = 6k + 2$ 
  - $-\sin \frac{\pi}{6} (6k + 2) + \sin \frac{5\pi}{6} (6k + 2) + \sin \frac{7\pi}{6} (6k + 2) - \sin \frac{11\pi}{6} (6k + 2) = 0$



# ダイオード整流回路

## 三相全波整流回路 直流定電流

- $i = 6k + 3$ 
  - $-\sin \frac{\pi}{6}(6k + 3) + \sin \frac{5\pi}{6}(6k + 3) + \sin \frac{7\pi}{6}(6k + 3) - \sin \frac{11\pi}{6}(6k + 3) = 0$
- $i = 6k + 4$ 
  - $-\sin \frac{\pi}{6}(6k + 4) + \sin \frac{5\pi}{6}(6k + 4) + \sin \frac{7\pi}{6}(6k + 4) - \sin \frac{11\pi}{6}(6k + 4) = 0$
- $i = 6k + 5$ 
  - $-\sin \frac{\pi}{6}(6k + 5) + \sin \frac{5\pi}{6}(6k + 5) + \sin \frac{7\pi}{6}(6k + 5) - \sin \frac{11\pi}{6}(6k + 5) = 0$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- $i = 6k$ 
  - $\cos \frac{\pi}{6} 6k - \cos \frac{5\pi}{6} 6k - \cos \frac{7\pi}{6} 6k + \cos \frac{11\pi}{6} 6k = 0$
- $i = 6k + 1$ 
  - $\cos \frac{\pi}{6} (6k + 1) - \cos \frac{5\pi}{6} (6k + 1) - \cos \frac{7\pi}{6} (6k + 1) + \cos \frac{11\pi}{6} (6k + 1) = 2\sqrt{3} \cos \pi k = 2\sqrt{3}(-1)^k$
- $i = 6k + 2$ 
  - $\cos \frac{\pi}{6} (6k + 2) - \cos \frac{5\pi}{6} (6k + 2) - \cos \frac{7\pi}{6} (6k + 2) + \cos \frac{11\pi}{6} (6k + 2) = 0$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- $i = 6k + 3$ 
  - $\cos \frac{\pi}{6}(6k + 3) - \cos \frac{5\pi}{6}(6k + 3) - \cos \frac{7\pi}{6}(6k + 3) + \cos \frac{11\pi}{6}(6k + 3) = 0$
- $i = 6k + 4$ 
  - $\cos \frac{\pi}{6}(6k + 4) - \cos \frac{5\pi}{6}(6k + 4) - \cos \frac{7\pi}{6}(6k + 4) + \cos \frac{11\pi}{6}(6k + 4) = 0$
- $i = 6k + 5$ 
  - $\cos \frac{\pi}{6}(6k + 5) - \cos \frac{5\pi}{6}(6k + 5) - \cos \frac{7\pi}{6}(6k + 5) + \cos \frac{11\pi}{6}(6k + 5) = -2\sqrt{3} \cos \pi k = -2\sqrt{3}(-1)^k$

# ダイオード整流回路

## 三相全波整流回路 直流定電流

- $$i_o = \frac{I_o}{2\pi} \sum_{k=0}^{\infty} \left[ \frac{\sqrt{3}(-1)^k}{6k+1} \sin(6k+1)\omega t - \frac{\sqrt{3}(-1)^k}{6k+5} \sin(6k+5)\omega t \right]$$
- $6k \pm 1$ の高調波