

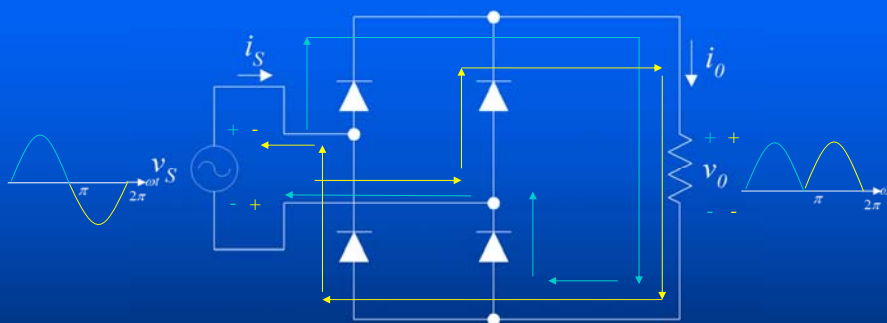
## 제 4 장 전파 정류기와 3상 정류기

### *Full-wave Rectifier & 3-Phase Rectifier AC → DC*

## 4.1 개요

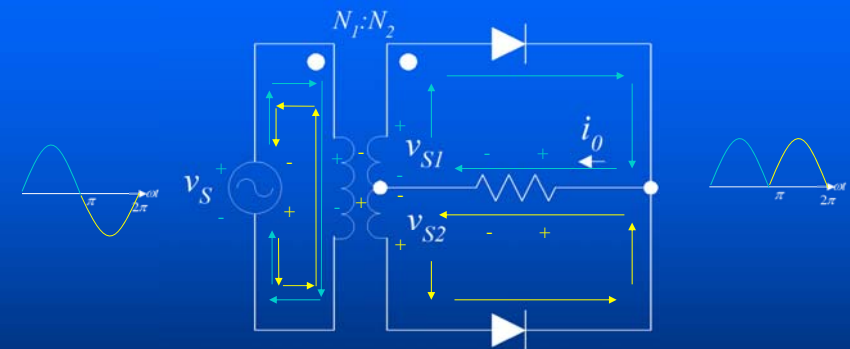
- 교류전원의 평균전류가 0
- 반파정류기보다 맥동 (Ripple)이 훨씬 적다
- 종류
  - 브리지 정류기(Bridge Rectifier)
  - 중간탭 변압기 정류기 (Center-tapped transformer rectifier)

## 4.2 단상전파정류기: 브리지형



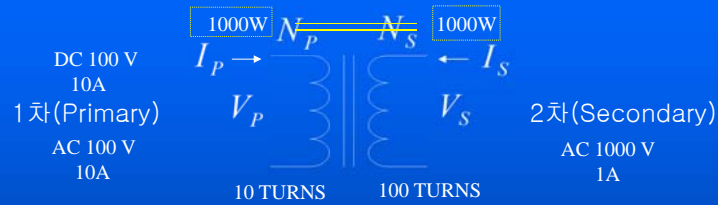
- 양방향으로 전류가 흐름

## 4.2 단상전파정류기: 중간탭형



- 양방향으로 전류가 흐름

## 변압기 모델: 전압, 전류



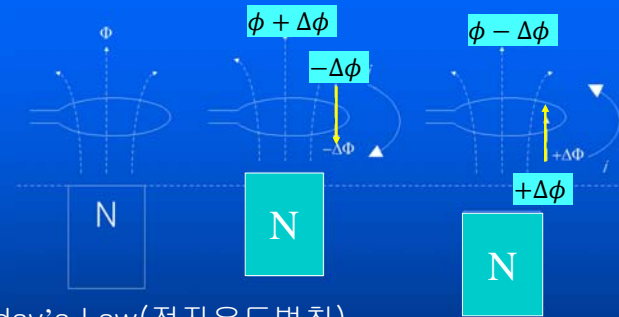
### ■ 전압, 전류

$$V_P = N_P \frac{d\phi}{dt}, V_S = N_S \frac{d\phi}{dt}, \therefore \frac{V_P}{V_S} = \frac{N_P}{N_S} \frac{d\phi}{dt} = \frac{N_P}{N_S}$$

### ■ 권수비

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P} = a \quad \therefore V_P I_P = V_S I_S$$

## 전자유도



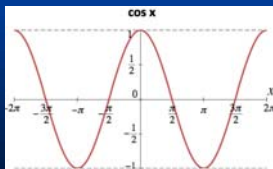
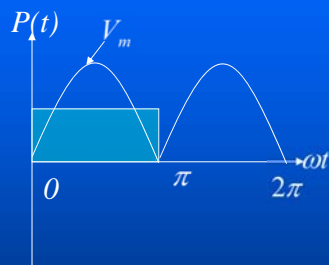
### ■ Faraday's Law (전자유도법칙)

$$emf = - \frac{d\phi}{dt}$$

Lentz's Law

- 기전력, **emf: electromotive force**
- 자속이 증가: 반대 방향으로 감소되는 자속이 발생하여 암페어의 법칙에 따라 전류가 흐름
- 자속이 감소: 반대 방향으로 증가되는 자속이 발생하여 암페어의 법칙에 따라 전류가 흐름

## 4.2 단상전파정류기: R부하 전류 평균값



$$V_0 = \frac{1}{T} \int_{t_0}^{t_0+T} v(t) dt$$

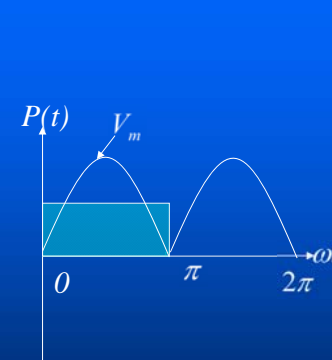
$$V_0 = \frac{1}{\pi} \int_0^{\pi} V_m \sin \omega t d(\omega t)$$

$$= \frac{V_m}{\pi} [-\cos \omega t]_0^{\pi} \quad \int \sin dt = -\cos t$$

$$= \frac{V_m}{\pi} (-\cos \pi + \cos 0)$$

$$= \frac{2V_m}{\pi}$$

## 4.2 단상전파정류기: R부하 전류 실효값



$$V_{rms} = \sqrt{\frac{1}{\pi} \int_0^{\pi} (V_m \sin \omega t)^2 d(\omega t)}$$

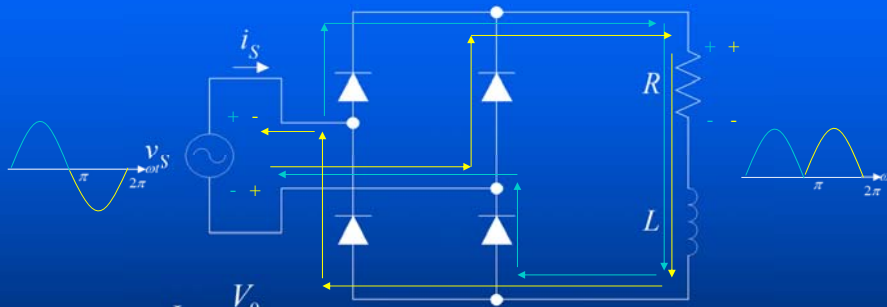
$$\left[ \sin^2 \omega t = \frac{1 - \cos 2\omega t}{2} \right]$$

$$= \sqrt{\frac{V_m^2}{\pi} \left[ \frac{\omega t}{2} - \frac{\sin 2\omega t}{4} \right]_0^{\pi}}$$

$$= \sqrt{\frac{V_m^2}{\pi} \left( \frac{\pi}{2} - \frac{\sin 2\pi}{4} - \frac{0}{2} + \frac{\sin 0}{4} \right)}$$

$$= \frac{V_m}{\sqrt{2}}$$

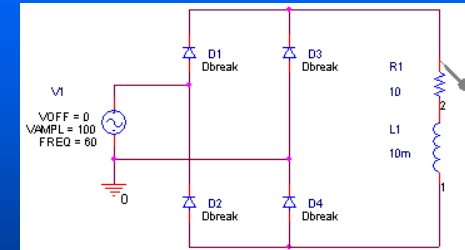
## 4.2 단상전파정류기 : R-L 부하



$$I_0 = \frac{V_0}{R}$$

$$I_n = \frac{V_n}{Z_n} = \frac{V_n}{|R + jn\omega L|}$$

## 예제 4-2 R-L 부하의 전파정류기



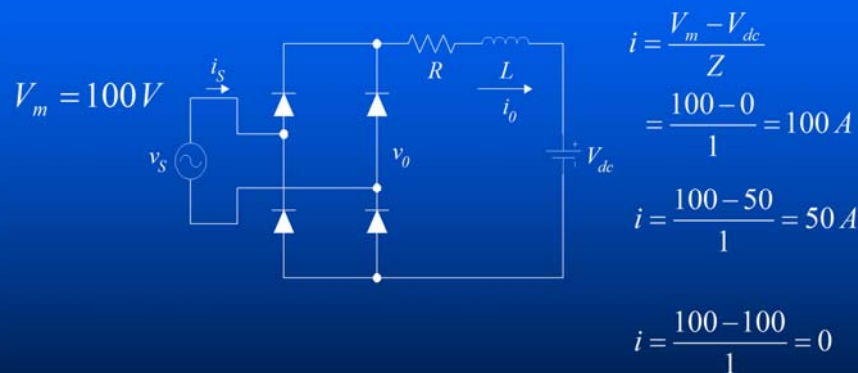
### Parameter

- ✓  $R = 10 \Omega$
- ✓  $L = 10 \text{ mH}$
- ✓  $f = 60 \text{ Hz}$
- ✓  $V_m = 100 \text{ V}$
- ✓ Transient Step = 0 50 ms

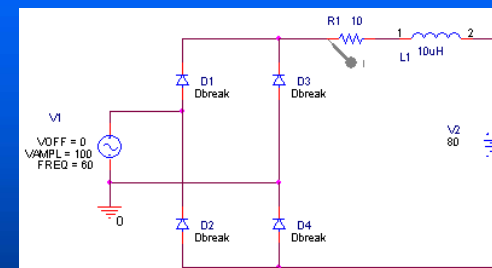
### Find

- ✓  $I, I_{avg}, I_{rms}$

## 4.2 단상전파정류기: R-L 기전력 부하



## 예제 4-3 R-L 전원부하의 전파정류기



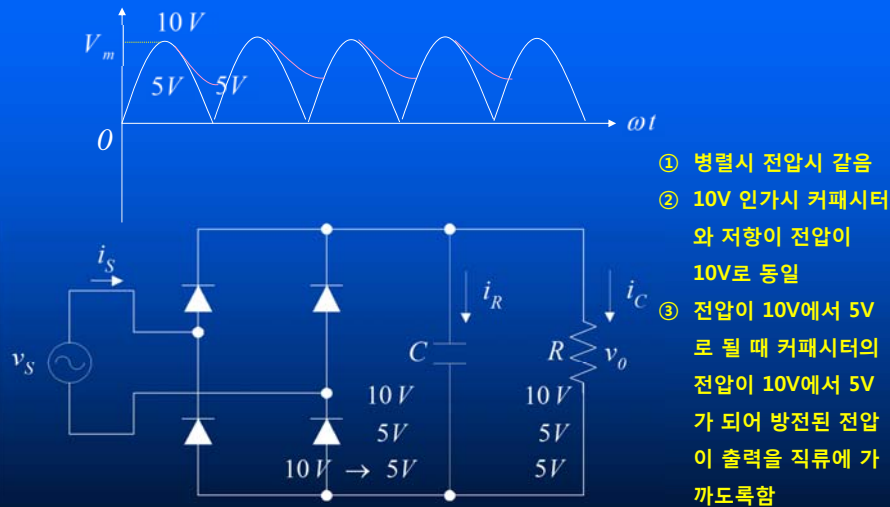
### Parameter

- ✓  $R = 2 \Omega$
- ✓  $L = 10 \text{ mH}$
- ✓  $f = 60 \text{ Hz}$
- ✓  $V_m = 100 \text{ V}$
- ✓  $V_{dc} = 80 \text{ V}$
- ✓ Transient Step = 0 50 ms

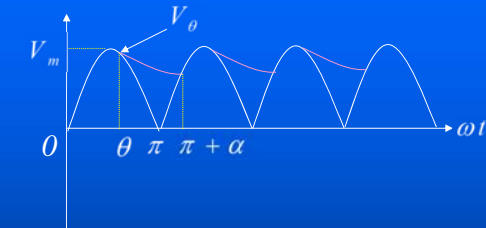
### Find

- ✓  $P, I_{avg}, I_{rms}$

## 4.2 단상전파정류기: R-C 부하



## 4.2 단상전파정류기: R-C 부하의 전류



$$V_o(\omega t) = \begin{cases} V_m \sin \omega t & \text{at diode on} \\ (V_m \sin \theta) e^{-\frac{(\omega t - \theta)}{\omega RC}} & \text{at diode off} \end{cases}$$

\*여기서  $V_\theta = V_m \sin \theta$ ,  $\theta = \tan^{-1}(-R \cdot \omega C)$

## 4.2 단상전파정류기: R-C 부하의 점화각

### ■ 점화각 (Firing Angle)

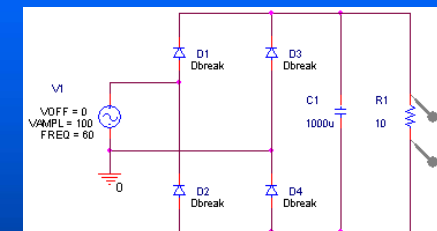
for  $\omega t = \alpha$

$$V_m \sin(\pi + \alpha) = (V_m \sin \theta) e^{-\frac{(\pi + \alpha - \theta)}{\omega RC}}$$

### ■ $\alpha$ 의 계산

- 수치기법(Numerical Analysis) 이용
- 수학적으로 계산
- Pspice를 이용하여 계산: 가장 간편함

## 예제 4-5 L-C 필터가 있는 전파정류기



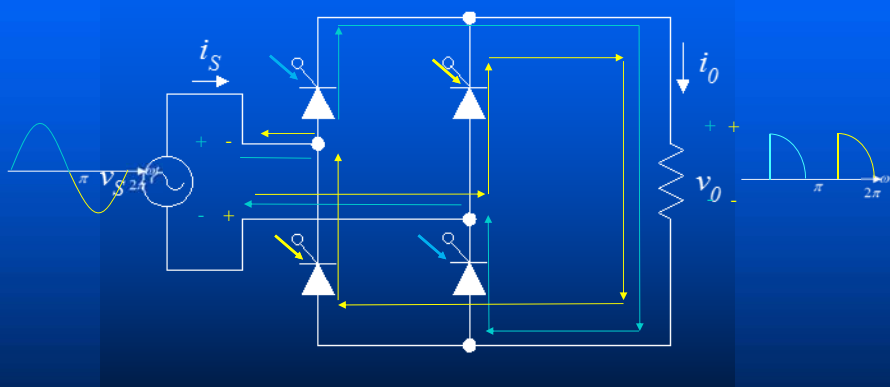
### ■ Parameter

- ✓  $R=10 \Omega$
- ✓  $L=5 \text{ mH}$
- ✓  $C=1000 \mu\text{F}$
- ✓  $f=60 \text{ Hz}$
- ✓  $V_m=100 \text{ V}$
- ✓ Transient Step  
=0 50 ms

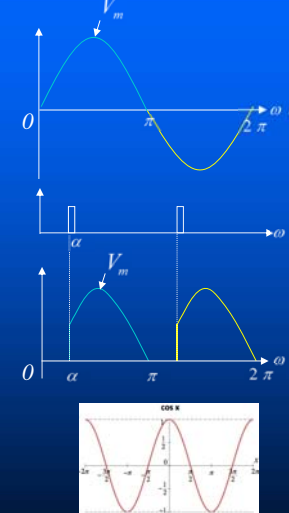
### ■ Find

- ✓ V

### 4.3 전파제어정류회로



### 4.3 전파제어저항회로: 평균값



$$V_0 = \frac{1}{T} \int_{t_0}^{t_0+T} v(t) dt$$

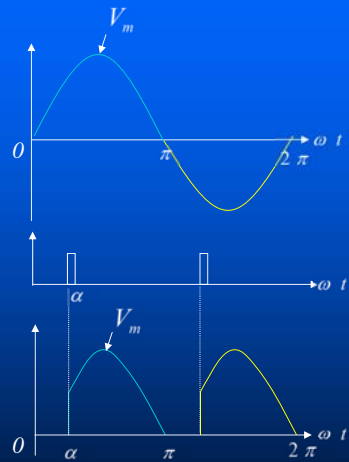
$$V_0 = \frac{1}{\pi} \int_{\alpha}^{\pi} V_m \sin \omega t d(\omega t)$$

$$\int \sin dt = -\cos t$$

$$= \frac{V_m}{\pi} [-\cos \omega t]_{\alpha}^{\pi}$$

$$= \frac{V_m}{\pi} (1 + \cos \alpha)$$

### 4.3 전파제어저항회로: 실효값



$$V_{rms} = \sqrt{\frac{1}{\pi} \int_{\alpha}^{\pi} (V_m \sin \omega t)^2 d(\omega t)}$$

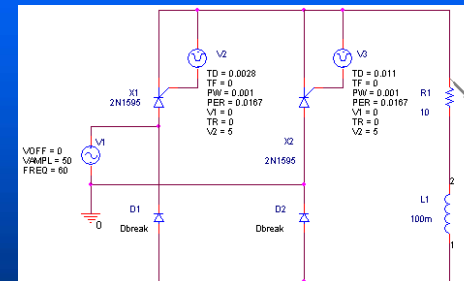
$$\sin^2 \omega t = \frac{1 - \cos 2\omega t}{2}$$

$$= \sqrt{\frac{V_m^2}{\pi} \left[ \frac{\omega t}{2} - \frac{\sin 2\omega t}{4} \right]_{\alpha}^{\pi}}$$

$$= \sqrt{\frac{V_m^2}{\pi} \left( \frac{\pi}{2} - \frac{\sin 2\pi}{4} - \frac{\alpha}{2} + \frac{\sin 2\alpha}{4} \right)}$$

$$= V_m \sqrt{\left( \frac{1}{2} - \frac{\alpha}{2\pi} + \frac{\sin(2\alpha)}{4\pi} \right)}$$

### 예제 4-9 전파제어정류기

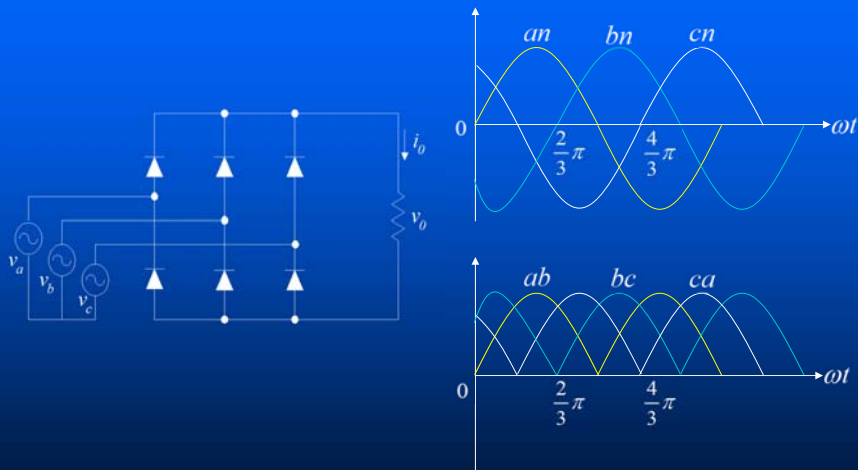


#### Parameter

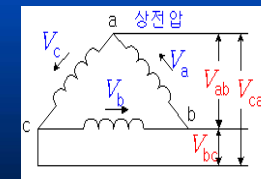
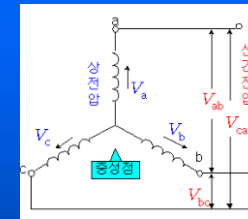
- ✓  $R=10 \Omega$
- ✓  $L=100 \text{ mH}$
- ✓  $f=60 \text{ Hz}$
- ✓  $\alpha=60$ 
  - $TD1:0.0028(1/360)$
  - $TD2:0.011(4/360)$
- ✓  $V_m=169.7 \text{ V} \rightarrow 50 \text{ V}$
- ✓ Transient Step
  - $=0.50 \text{ ms}$

Find:  $i, i_{avg}, P$

## 4.4 3상 정류회로

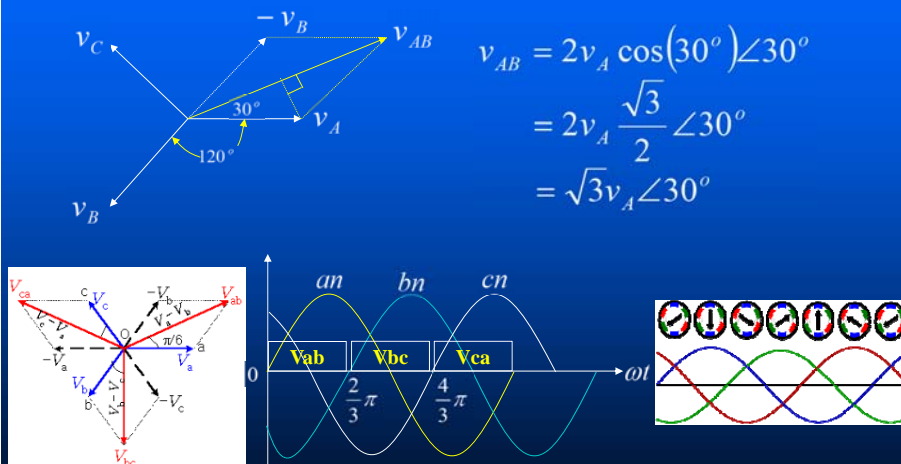


## 3상 회로



결선	선간 전압	선간 전류	전력
Y	$\sqrt{3} \times$ 상전압	상전류	$\sqrt{3} \times$ 상전압 $\times$ 상전류
Δ	상전압	$\sqrt{3} \times$ 상전류	$\sqrt{3} \times$ 상전압 $\times$ 상전류

## 4.4 3상 회로: 전압



## 4.4 3상 정류회로: Fourier 변환

### 직류 성분

$$V_0(t) = V_0 + \sum_{n=6,12,18} V_n \cos(n\omega_0 t + \pi)$$

$$V_0 = \frac{1}{\pi/3} \int_{\pi/3}^{2\pi/3} V_{m,L-L} \sin \omega t d(\omega t) = \frac{V_{m,L-L}}{\pi/3} \left[ -\cos \omega t \right]_{\pi/3}^{2\pi/3}$$

$$= \frac{V_{m,L-L}}{\pi/3} \left\{ -\cos \frac{2\pi}{3} + \cos \frac{\pi}{3} \right\} = \frac{V_{m,L-L}}{\pi/3} \left\{ -\left(-\frac{1}{2}\right) + \frac{1}{2} \right\}$$

$$= \frac{3V_{m,L-L}}{\pi} = 0.95V_{m,L-L}$$

### 고조파 성분

$$V_n = \frac{V_l}{\pi(n^2 - 1)}, \quad n = 6, 12, 18$$

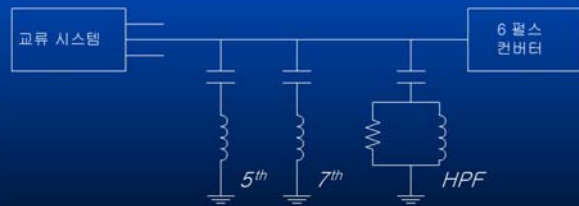
## 4.4 3상 정류회로: 선전류

### ■ 선전류

$$i_a(t) = \frac{2\sqrt{3}}{\pi} I_0 (\cos \omega_0 t - \frac{1}{5} \cos 5\omega_0 t + \frac{1}{7} \cos 7\omega_0 t - \dots)$$

### ■ 고조파를 제거하는 방법

- 입력 Filter를 사용



## 예제 4-12 3상 정류기(1)



### (a) 출력 직류전압

$$V_0 = \frac{3V_{m,L-L}}{\pi} = \frac{3\sqrt{2}(480)}{\pi} = 648V$$

### (b) 평균 부하전류

$$I_0 = \frac{V_0}{R} = \frac{648}{25} = 25.9 A$$

### (c) 다이오드의 평균값과 실효값

$$I_{D,avg} = \frac{I_0}{3} = \frac{25.9}{3} = 8.63 A$$

$$I_{D,rms} = \frac{I_{0,rms}}{\sqrt{3}} \approx \frac{25.9}{\sqrt{3}} = 15.0 A$$

## 예제 4-12 3상 정류기(2)



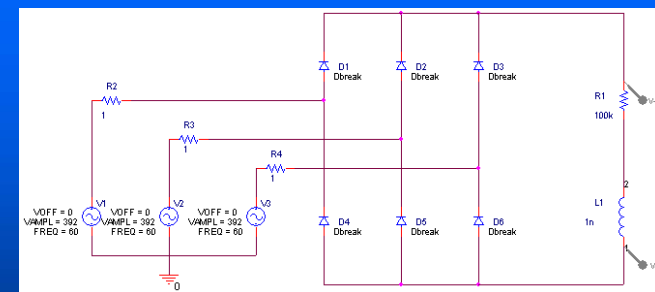
### (d) 전원의 실효값

$$I_{s,avg} = \sqrt{\frac{2}{3}} I_{0,rms} \approx \sqrt{\frac{2}{3}} (25.9) = 21.2 A$$

### (e) 전원의 피상전력

$$S = \sqrt{3} V_{L-L,rms} I_{0,rms} = \sqrt{3} (480) (21.2) = 17.6 KVA$$

## 예제 4-12 3상 정류기: Pspice Simulation



### ■ Parameter

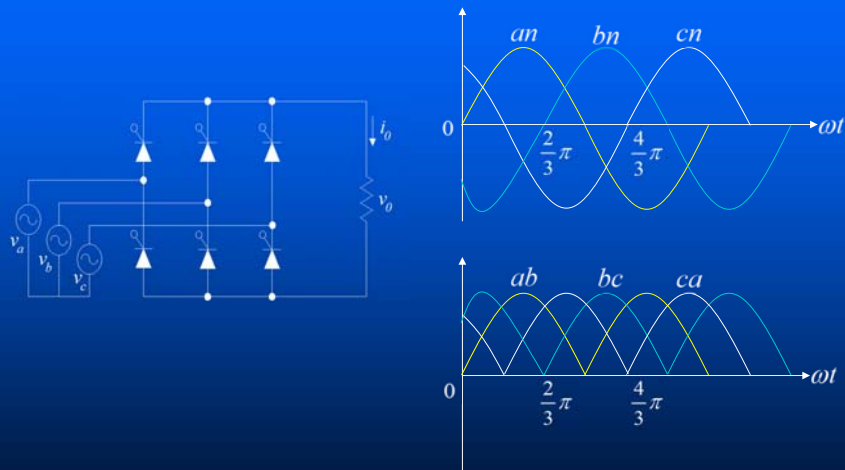
$$R=100 k\Omega \quad L=50 mH \quad f=60 Hz$$

$$V_m = \frac{\sqrt{2}(480)}{\sqrt{3}} = 392 \quad Step=0:0.1 ms:50 ms$$

### ■ Find : $V_0, I_{avg}, I_{rms}$



## 4.5 3상 제어정류회로



## 4.5.2 3상 제어정류회로: 평균전압

$$\begin{aligned}
 V_0 &= \frac{1}{\pi/3} \int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_{m,L-L} \sin \omega t d(\omega t) \\
 &= \frac{V_{m,L-L}}{\pi/3} \left[ -\cos \omega t \right]_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} \\
 &= \frac{V_{m,L-L}}{\pi/3} \left\{ -\cos \left( \frac{2\pi}{3} + \alpha \right) + \cos \left( \frac{\pi}{3} + \alpha \right) \right\} \quad \boxed{\cos \frac{2\pi}{3} = -\cos \frac{\pi}{3}} \\
 &= \frac{V_{m,L-L}}{\pi/3} \left\{ \cos \left( \frac{\pi}{3} - \alpha \right) + \cos \left( \frac{\pi}{3} + \alpha \right) \right\} \quad \boxed{\begin{aligned} \cos(x+y) &= \cos x \cos y - \sin x \sin y \\ \cos(x-y) &= \cos x \cos y + \sin x \sin y \end{aligned}} \\
 &= \frac{V_{m,L-L}}{\pi/3} \left\{ \cos \frac{\pi}{3} \cos \alpha + \sin \frac{\pi}{3} \sin \alpha + \cos \frac{\pi}{3} \cos \alpha - \sin \frac{\pi}{3} \sin \alpha \right\} \\
 &= \frac{3V_{m,L-L}}{\pi} 2 \cos \frac{\pi}{3} \cos \alpha = \frac{3V_{m,L-L}}{\pi} \cos \alpha
 \end{aligned}$$

## 4.5.2 3상 제어정류회로(2)

### ■ 평균전압

$$V_0 = \frac{1}{\pi/3} \int_{\frac{\pi}{3}+\alpha}^{\frac{2\pi}{3}+\alpha} V_l \sin \omega t d(\omega t) = \frac{3V_l}{\pi} \cos \alpha$$

### ■ 12상 Pulse의 평균전압

$$V_0 = V_{0Y} + V_{0\Delta} = \frac{6V_l}{\pi} \cos \alpha$$

### ■ 12상 Pulse의 선전류

$$i_{ac}(t) = i_Y(t) + i_{\Delta}(t) = \frac{4\sqrt{3}}{\pi} \left( \cos \omega_0 t - \frac{1}{11} \cos 11\omega_0 t + \dots \right)$$

## 4.6 직류 송전

