제 3 장 반파 정류기

Half-wave Rectifier

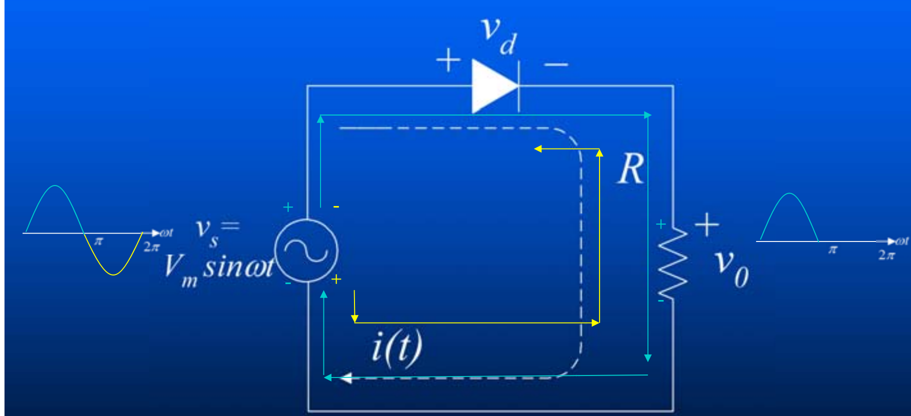
AC→ DC

3장 반파정류회로의 구성

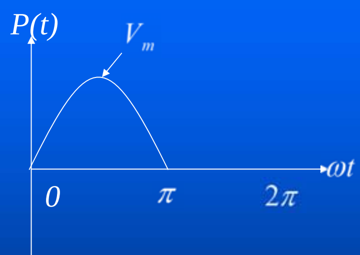
3.1 서론

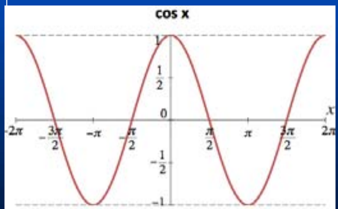
- 정류(Rectification)
  - AC→DC로 변환
- 반파 정류
  - − 공급되는 전류 평균: 0이 아님
  - − 변압기 성능에 문제점 유발 가능
  - − 실제로는 전파 전류가 주로 이용
- OrCAD를 이용하여 계산: 가장 간편함

3.2 저항부하(Resistive Load)



3.2 저항부하: 반파의 평균값





- 전압의 평균값

$$V_0 = \frac{1}{2\pi}\int_0^\pi V_m \sin\omega t \, d(\omega t)$$

$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^\pi \qquad \int \sin dt = -\cos t$$

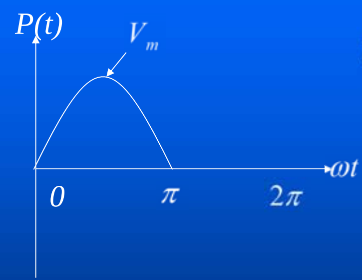
$$= \frac{V_m}{2\pi}\left(-\cos\pi - (-\cos 0)\right)$$

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

- 전류의 직류 성분

$$I = \frac{V_0}{R} = \frac{V_m}{\pi R}$$

3.2 저항부하: 반파의 실효값



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

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

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

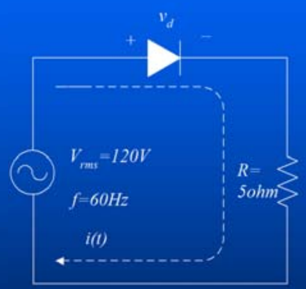
$$= \sqrt{\frac{V_m^2}{2\pi}\left(\frac{\pi}{2} - \frac{\sin 2\pi}{4} - \frac{0}{2} + \frac{\sin 0}{4}\right)} = \frac{V_m}{\sqrt{2}}$$

- 전류의 실효값

$$I_R = \frac{V_{rms}}{R} = \frac{V_m}{2R}$$

예제 3-1 저항부하를 가진 반파정류기(1)

(a) 평균 전류



$$V_0 = \frac{1}{2\pi}\int_0^\pi V_m \sin\omega t \, d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^\pi \sqrt{2}(120)\sin\omega t \, d(\omega t)$$

$$= \frac{\sqrt{2}(120)}{2\pi}\left[-\cos\omega t\right]_0^\pi$$

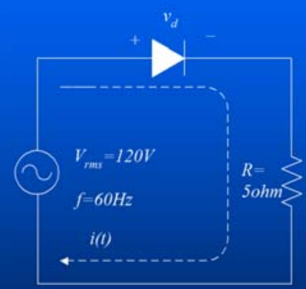
$$= \frac{\sqrt{2}(120)}{2\pi}\left(-\cos\pi + \cos 0\right)$$

$$= \frac{\sqrt{2}(120)}{\pi} = 54.02[V]$$

$$\therefore I = \frac{V_0}{R} = \frac{54.02}{5} = 10.8[A]$$

예제 3-1 저항부하를 가진 반파정류기(2)

(b) 실효 전압



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

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

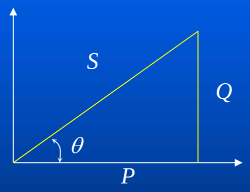
$$= \sqrt{\frac{V_m^2}{2\pi}\left[\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right]_0^\pi}$$

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

$$= \frac{\sqrt{2}(120)}{2} = 84.9V$$

예제 3-1 저항부하를 가진 반파정류기(3)

(c) 역률

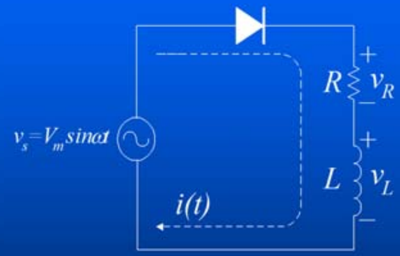


$$P = \frac{V_{rms}^{2}}{R} = \frac{84.9^2}{4} = 1440W$$

$$I_{rms} = \frac{V_m}{2R} = \frac{\sqrt{2}(120)}{2(5)} = 17\,A$$

$$pf = \frac{p}{V_{rms} I_{rms}} = \frac{1440}{(120)(17)} = 0.707$$

3.3 R-L 부하



- By KVL

$$L\frac{di}{dt} + Ri = V_m \sin\omega t$$

$$\omega L\frac{di}{d\omega t} + Ri = V_m \sin\omega t$$

3.3 R-L 부하: 전류계산(1)

$$\omega L\frac{di}{d\omega t} + Ri = V_m \sin\omega t \qquad \boxed{\times \frac{1}{\omega L}}$$

$$\frac{di}{dt} + \frac{R}{\omega L} i = \frac{V_m}{\omega L} \sin\omega t \qquad \boxed{\times e^{\frac{R}{\omega L}\omega t}}$$

$$\frac{di}{d\omega t} e^{\frac{R}{\omega L}\omega t} + \frac{R}{\omega L} e^{\frac{R}{\omega L}\omega t} i = \frac{V_m}{\omega L} e^{\frac{R}{\omega L}\omega t} \sin\omega t$$

$$\frac{d}{d\omega t}\left(i e^{\frac{R}{\omega L}\omega t} \right) = \frac{V_m}{\omega L} e^{\frac{R}{\omega L}\omega t} \sin\omega t\, d\omega t \qquad \boxed{d(A\cdot B) = dA\cdot B + A\cdot dB}$$

$$i e^{\frac{R}{\omega L}\omega t} = \int \frac{V_m}{\omega L} e^{\frac{R}{\omega L}\omega t} \sin\omega t\, d\omega t + A$$

3.3 R-L 부하: 전류계산(2)

$$i e^{\frac{R}{\omega L}\omega t} = \int \frac{V_m}{\omega L} e^{\frac{R}{\omega L}\omega t} \sin\omega t\, d\omega t + A \qquad \boxed{\times e^{-\frac{R}{\omega L}\omega t}}$$

$$i = e^{-\frac{R}{\omega L}\omega t} \frac{V_m}{\omega L} \int e^{\frac{R}{\omega L}\omega t} \sin\omega t\, d\omega t + A e^{-\frac{R}{\omega L}\omega t}$$

$$\boxed{\int e^{au} \sin bu\, du = \frac{e^{au}(a \sin bu - b\cos bu)}{a^2 + b^2}}$$

$$i = e^{-\frac{R}{\omega L}\omega t} \frac{V_m}{\omega L} \frac{e^{\left(\frac{R}{\omega L}\right)\omega t}\left(\left(\frac{R}{\omega L}\right)\sin\omega t - \cos\omega t\right)}{\left(\frac{R}{\omega L}\right)^2 + 1^2} + A e^{-\frac{R}{\omega L}\omega t}$$

3.3 R-L 부하: 전류계산(3)

$$i = e^{-\frac{R}{\omega L}\omega t}\frac{V_m}{\omega L}\frac{e^{\left(\frac{R}{\omega L}\right)\omega t}\left(\left(\frac{R}{\omega L}\right)\sin\omega t-\cos\omega t\right)}{\left(\frac{R}{\omega L}\right)^2+1^2}+Ae^{-\frac{R}{\omega L}\omega t}$$

$$=\frac{V_m}{\omega L}\frac{\left(\left(\frac{R}{\omega L}\right)\sin\omega t-\cos\omega t\right)}{\left(\frac{R^2+(\omega L)^2}{(\omega L)^2}\right)}+Ae^{-\frac{R}{\omega L}\omega t}$$

$$=\frac{V_m}{\left(R^2+(\omega L)^2\right)}\left(R\sin\omega t-\omega L\cos\omega t\right)+Ae^{-\frac{R}{\omega L}\omega t}$$

3.3 R-L 부하: 전류계산(4)

$$i=\frac{V_m}{\left(R^2+(\omega L)^2\right)}\left(R\sin\omega t-\omega L\cos\omega t\right)+Ae^{-\frac{R}{\omega L}\omega t}$$

$$a\cos x+b\sin x=\sqrt{a^2+b^2}\sin(x+\delta),\ \delta=\tan^{-1}\frac{a}{b}$$

$$i=\frac{V_m\sqrt{\left(R^2+(\omega L)^2\right)}}{\left(R^2+(\omega L)^2\right)}\sin(\omega t-\theta)+Ae^{-\frac{R}{\omega L}\omega t}$$

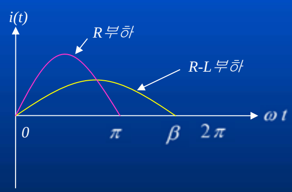
$$=\frac{V_m}{\sqrt{\left(R^2+(\omega L)^2\right)}}\sin(\omega t-\theta)+Ae^{-\frac{R}{\omega L}\omega t}=\frac{V_m}{Z}\sin(\omega t-\theta)+Ae^{-\frac{R}{\omega L}\omega t}$$

$$where\ Z=\sqrt{\left(R^2+(\omega L)^2\right)},\ \theta=\tan^{-1}\frac{\omega L}{R}$$

3.3 R-L 부하: 전류계산(5)

$$i=\frac{V_m}{Z}\sin(\omega t-\theta)+Ae^{-\frac{R}{\omega L}\omega t}$$

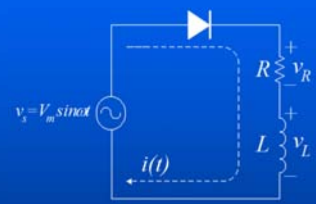
- A를 구하기 위한 초기조건 $\omega t=0$ 일 때 $i=0$



$$Ae^{-0}=0-\frac{V_m}{Z}\sin(0-\theta)=\frac{V_m}{Z}\sin(\theta)$$

$$\therefore i=\frac{V_m}{Z}\left[\sin(\omega t-\theta)+\sin\theta\, e^{-\frac{R}{L}t}\right]$$

3.3 R-L 부하: 정상과 과도



- By KVL

$$L\frac{di}{dt}+Ri=V_m\sin\omega t$$

- 전류값

$$i(t)=\frac{V_m}{Z}\left[\sin(\omega t-\theta)+\sin\theta\cdot e^{-\frac{R}{L}t}\right]$$

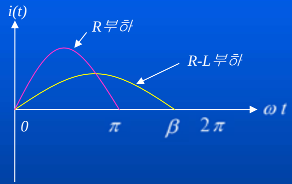
- 전류=정상치+과도치

$$i(t)=i_f(t)+i_n(t)$$

*여기서 $i_f=\frac{V_m}{Z}\sin(\omega t-\theta),\ i_n=\frac{V_m}{Z}\sin\theta e^{-\frac{R}{L}t}$

3.3 R-L 부하: 소호각 계산

- β: 소호각(Extinction Angle)



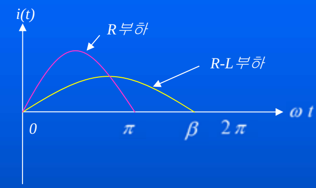
$$i(t) = \frac{V_m}{Z}\left[\sin(\omega t - \theta) + \sin\theta \cdot e^{-\frac{R}{L}t}\right]$$

$$i(\beta) = 0 = \frac{V_m}{Z}\left[\sin(\beta t - \theta) + \sin\theta \cdot e^{-\frac{R\beta}{L\omega}t}\right]$$

$$\therefore \sin(\beta t - \theta) + \sin\theta \cdot e^{-\frac{R\beta}{L\omega}t} = 0$$

- β의 계산
  - 수치기법(Numerical Analysis) 이용계산
  - OrCAD를 이용하여 계산: 가장 간편함

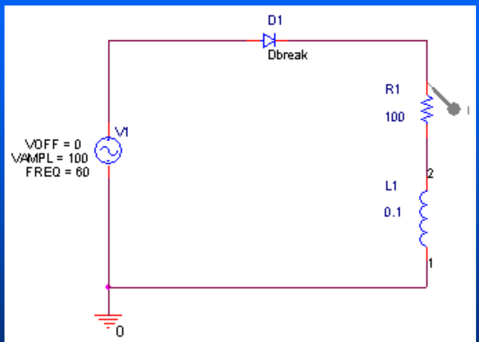
3.3 R-L 부하: 종합



$$i(\omega t) = \begin{cases} \frac{V_m}{Z}\left[\sin(\omega t - \theta) + \sin\theta \cdot e^{-\frac{R}{L}t}\right] & at\ 0 \le \omega t \le \beta \\ 0 & at\ \beta \le \omega t \le 2\pi \end{cases}$$

*여기서 $Z = \sqrt{R^2 + (\omega L)^2}$, $\theta = \tan^{-1}\left(\frac{L}{R}\right)$

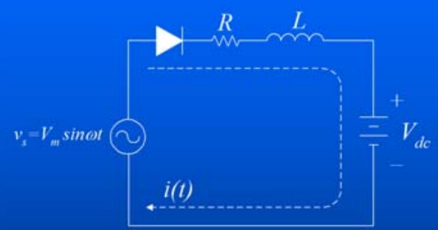
예제 3-3 R-L 부하를 가진 반파정류기



- *Parameter*
  - ✓ *R=100 Ω*
  - ✓ *L=0.1 H*
  - ✓ *ω=377 rad/s, f=ω/2π=60 Hz*
  - ✓ V_m*=100 V*
  - ✓ *Transient:*
    0 0.01m 50ms

3.5 R-L 기전력부하

$V_m = 100V$



$$i = \frac{V_m - V_{dc}}{Z} = \frac{100-0}{1} = 100\,A$$

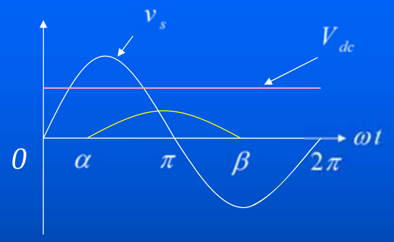
$$i = \frac{100-50}{1} = 50\,A$$

- By KVL

$$V_m \sin\omega t = Ri + L\frac{di}{dt} + V_{dc}$$

$$i = \frac{100-100}{1} = 0$$

3.5 R-L 기전력: 전류



$$V_m \sin\alpha = V_{dc}$$

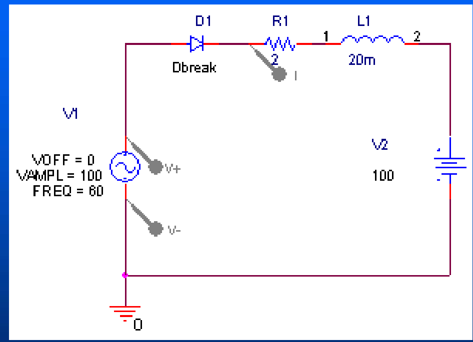
$$\therefore \alpha = \sin^{-1}\left(\frac{V_{dc}}{V_m}\right)$$

- 전류

$$i(\omega t) = \frac{V_m}{Z}\sin(\omega t-\theta) - \frac{V_{dc}}{R} + \left(-\frac{V_m}{Z}\sin(\alpha-\theta) + \frac{V_{dc}}{R}\right)e^{-\frac{\alpha}{\omega\tau}}$$

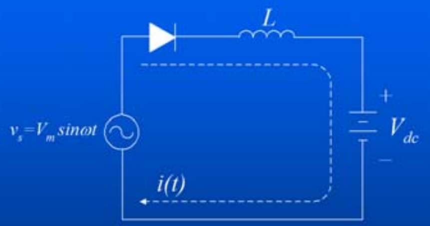
$$at\ \alpha \le \omega t \le \beta$$

예제 3-5 R-L 기전력부하 반파정류기



- *Parameter*
  - ✓ $R=2\ \Omega$
  - ✓ $L=20\ mH$
  - ✓ $f=\omega/2\pi=60\ Hz$
  - ✓ $V_m=169.7\ V$
  - ✓ $V_{dc}=100\ V$
  - ✓ *Transient:*
    0 0.01m 50ms

3.6 인덕터 기전력부하



- By KVL

$$V_m \sin\omega t = L\frac{di}{dt} + V_{dc}$$

$$V_m \sin\omega t = \omega L\frac{di}{d\omega t} + V_{dc}$$

3.6 인덕터 기전력부하: 전류

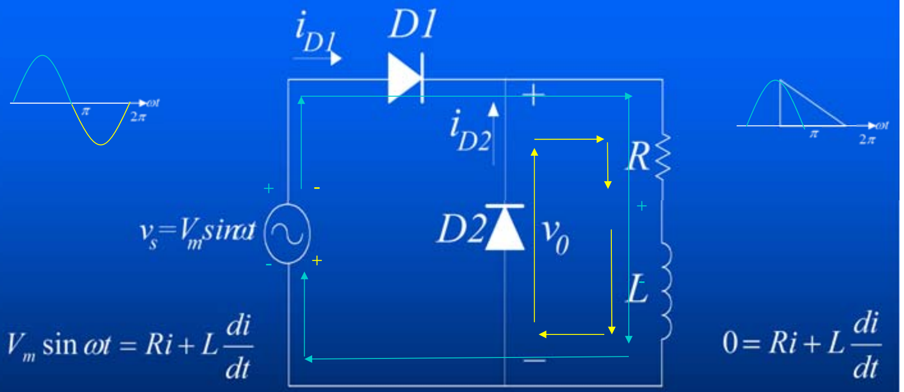
$$V_m \sin\omega t = \omega L\frac{di}{d\omega t} + V_{dc}$$

$$\frac{di}{d\omega t} = \frac{V_m \sin\omega t - V_{dc}}{\omega L}$$

$$i(\omega t) = \frac{1}{\omega L}\int_0^{\omega} V_m \sin\omega t\, d\omega t - \frac{1}{\omega L}\int_0^{\omega} V_{dc}\, d\omega t$$

$$i(\omega t) = \begin{cases} \frac{V_m}{\omega L}(\cos\alpha - \cos\omega t) + \frac{V_{dc}}{\omega L}(\alpha - \omega t) & at\ \alpha \le \omega t \le \beta \\ 0 \quad otherwise & \end{cases}$$

3.7 환류 다이오드(Freewheeling Diode)



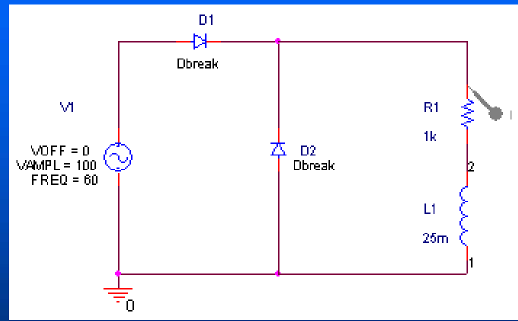
$$V_m \sin \omega t = Ri + L\frac{di}{dt}$$

$$0 = Ri + L\frac{di}{dt}$$

① +인가시 D1를 통하여 L에 전기가 저장

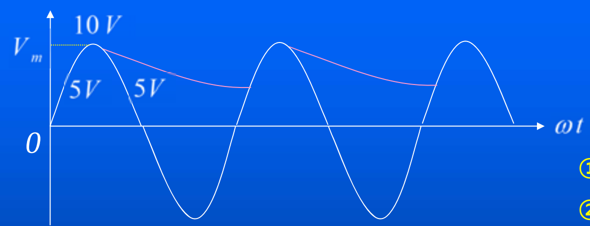
② -인가시 L에 저장된 전기가 방전되어 출력을 직류에 가깝도록함

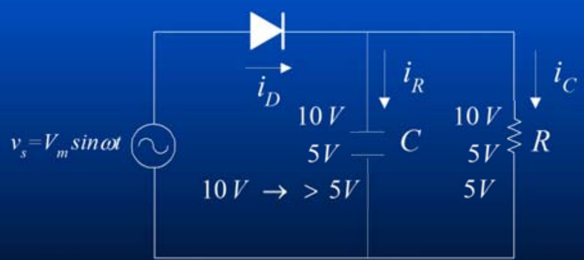
예제 3-7 환류다이오드를 가진 반파정류기



- Parameter
  - ✓ R=2 Ω
  - ✓ L=25 mH
  - ✓ f=60 Hz
  - ✓ V_m=100 V
  - ✓ Transient:
    0 1m 50m

3.8 R-C 반파정류회로



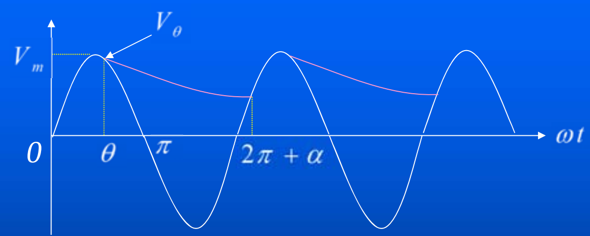


① 병렬시 전압이 같음

② 10V 인가시 커패시터와 저항이 전압이 10V로 동일

③ 전압이 10V에서 5V로 될 때 커패시터의 전압이 10V에서 5V가 되어 방전된 전압이 출력을 직류에 가깝도록함

3.8 R-C 반파: 전류(1)



$$V_0(\omega t) = \begin{cases} V_m \sin \omega t & \text{at diode on} \\ V_\theta \cdot e^{-\frac{(\omega t - \theta)}{\omega RC}} & \text{at diode off} \end{cases}$$

*여기서

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

3.8 R-C 반파: 전류(2)

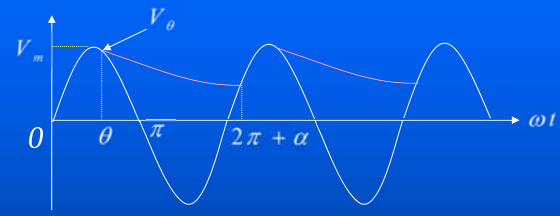
- 점화각 (Firing Angle)

$$for \quad \omega t = 2\pi + \alpha$$

$$V_m \sin(2\pi + \alpha) = (V_m \sin\theta) e^{-\frac{(2\pi + \alpha - \theta)}{\omega RC}}$$

- α의 계산
  - 수치기법(Numerical Analysis) 이용계산
  - OrCAD를 이용하여 계산: 가장 간편함

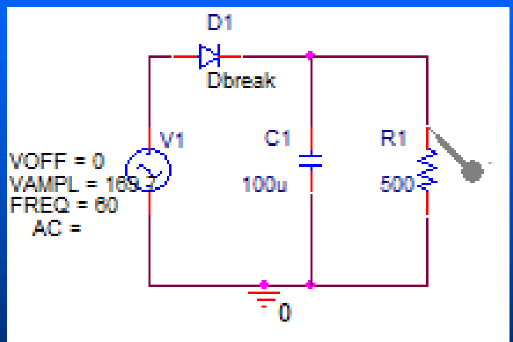
3.8 R-C 반파: 전류(3)



- C의 전류: $i_C = \omega C \dfrac{dV_0(\omega t)}{d(\omega t)}$

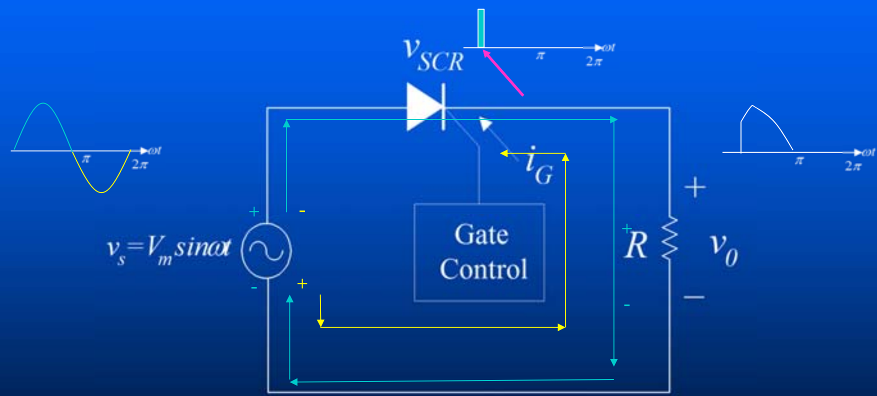
$$i_C(\omega t) = \begin{cases} \dfrac{V_m \sin\theta}{R} e^{-\frac{(\omega t - \theta)}{\omega RC}} & at \ 0 \le \omega t \le 2\pi + \alpha \\ \omega C V_m \cos(\omega t) & at \ 2\pi + \alpha \le \omega t \le 2\pi + \theta \end{cases}$$

예제 3-9 R-C 부하를 갖는 반파정류기

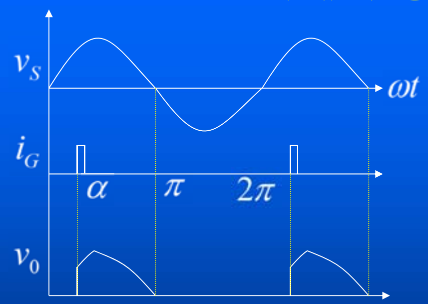


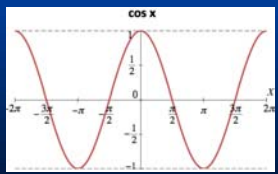
- *Parameter*
  - ✓ *R=500 Ω*
  - ✓ *C=100 μF*
  - ✓ *f=60 Hz*
  - ✓ V_m=100
  - ✓ *Transient:* *0 0.01m 50m*

3.9 반파제어 정류기



3.9 반파제어 정류기: 저항부하





- 전압의 평균값

$$V_0 = \frac{1}{2\pi}\int_\alpha^\pi V_m \sin\omega t\, d(\omega t)$$

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

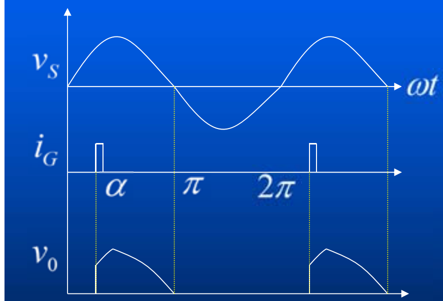
$$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_\alpha^\pi$$

$$= \frac{V_m}{2\pi}\left(-\cos\pi + \cos\alpha\right)$$

$$= \frac{V_m}{2\pi}\left(1 + \cos\alpha\right)$$

3.9 반파제어 정류기: 저항부하

- 전압의 실효값



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

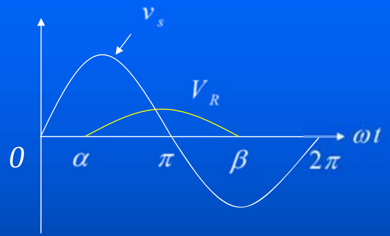
$$\left(\sin^2\omega t = \frac{1-\cos 2\omega t}{2}\right)$$

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

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

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

3.9 반파제어 정류기: R-L부하

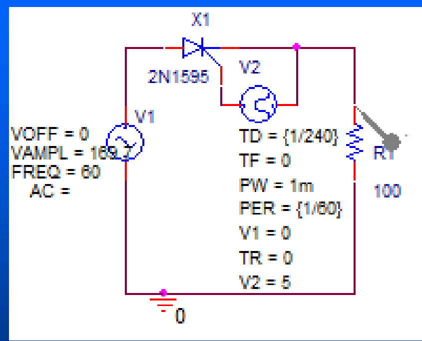


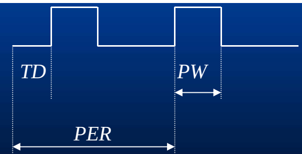
- 전류

$$i(\omega t) = i_f(\omega t) + i_n(\omega t)$$

$$i(\omega t) = \begin{cases} \dfrac{V_m}{Z}\left(\sin(\omega t - \theta) - \sin(\alpha - \theta)e^{-\frac{(\alpha-\omega t)}{\omega\tau}}\right) & at\ \alpha \le \omega t \le \beta \\ 0 & otherwise \end{cases}$$

3.10 OrCAD: 반파제어정류기 설계





- *Parameter*
  - ✓ *R=1 k Ω*
  - ✓ *f=ω/2π=60 Hz*
  - ✓ V_m=50 V
  - ✓ V_{pulse}
    - *V1=0 V*
    - *V2=5 V*
    - *TD=0*
    - *PER= 1/60={1/60}*
    - *PW=1m*
  - ✓ *Transient*

    0 0.01m 50m