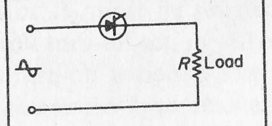
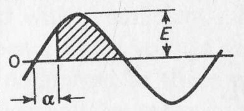
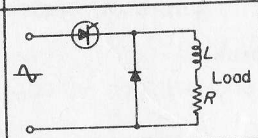
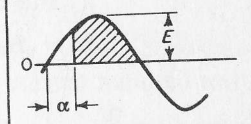
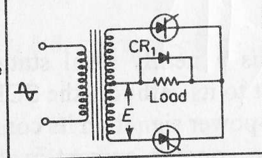
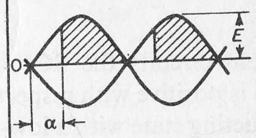
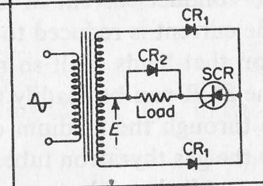
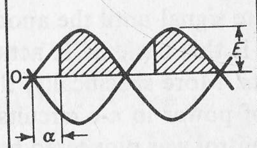
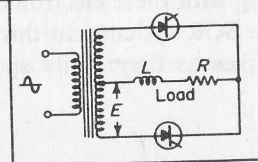
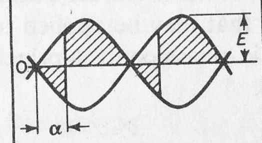
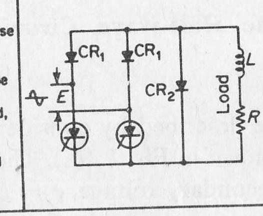
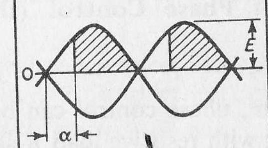
Chart 8.1 CIRCUIT CONSTANTS OF SOME MAJOR PHASE CONTROLLED CIRCUITS†

Circuit (a) Name	(b) Connections	(c) Load voltage waveforms	(d) Peak forward voltage on SCR	Peak reverse voltage (e) On SCR	Peak reverse voltage (f) On diode	(g) Max. load voltage ($\alpha = 0$) E_D = average d-c value; E_a = RMS a-c value
(1) Half-wave resistive load			E	E	—	$E_D = \frac{E}{\pi}$ $E_a = \frac{E}{2}$
(2) Half-wave inductive load with free-wheeling rectifier			E	E	E	$E_D = \frac{E}{\pi}$
(3) Centertap with resistive load, or inductive load with free-wheeling rectifier			E (possibly $2E$ if load open)	$2E$	E	$E_D = \frac{2E}{\pi}$
(4) Centertap with resistive or inductive load—SCR in d-c circuit			E	0	$2E$ on CR_1 / E on CR_2	$E_D = \frac{2E}{\pi}$
(5) Centertap with inductive load (no free-wheeling rectifier)			$2E$	$2E$	—	$E_D = \frac{2E}{\pi}$
(6) Single-phase bridge with 2 SCR's with common anode or cathode. Resistive load, or inductive load with free-wheeling rectifier			E	E	E (CR_1 and CR_2)	$E_D = \frac{2E}{\pi}$

† Assumes zero forward drop in semiconductors when conducting, and zero current when blocking; also zero a-c line and source reactance. Inductive d-c loads have pure d-c current.

Chart 8.1 (cont.)

(h) Load voltage vs trigger delay angle α	(j) Trigger angle range full ON to full OFF	Max. steady-state current in SCR (k) Average amp	Max. steady-state current in SCR (l) Cond. angle	Max. steady-state current in diode rectifier (m) Average amp	Max. steady-state current in diode rectifier (n) Cond. angle for max. current	(p) Ability to pumpback inductive load energy to supply line	(q) Fundamental frequency of load voltage (f = supply frequency)	(r) Notes and comments
$E_D = \frac{E}{2\pi}(1 + \cos\alpha)$ $E_a = \frac{E}{2\sqrt{\pi}}(\pi - \alpha + \frac{1}{2}\sin 2\alpha)^{1/2}$	180°	$\frac{E}{\pi R}$	180°	—	—	—	f	
$E_D = \frac{E}{2\pi}(1 + \cos\alpha)$	180°	$\frac{E}{2\pi R}$ (load highly inductive)	180°	$0.54\left(\frac{E}{\pi R}\right)$	210°	No	f	
$E_D = \frac{E}{\pi}(1 + \cos\alpha)$	180°	$\frac{E}{\pi R}$	180°	$0.26\left(\frac{2E}{\pi R}\right)$	148°	No	$2f$	
$E_D = \frac{E}{\pi}(1 + \cos\alpha)$	180°	$\frac{2E}{\pi R}$	360°	$CR_1 = \frac{E}{\pi R}$ / $CR_2 = 0.26\left(\frac{2E}{\pi R}\right)$ with highly inductive load	180° / 148°	No	$2f$	CR_2 necessary when load is not purely resistive. Frequency limited by recovery characteristics of rectifiers and SCR.
$E_D = \frac{2E}{\pi}\cos\alpha$ (assuming continuous current in load)	180°	$\frac{E}{\pi R}$	180°	—	—	Yes	$2f$	
$E_D = \frac{E}{\pi}(1 + \cos\alpha)$	180°	$\frac{E}{\pi R}$	180°	$CR_1 = \frac{E}{\pi R}$ / $CR_2 = 0.26\left(\frac{2E}{\pi R}\right)$	180° / 148°	No	$2f$	Without CR_2, SCR's may be unable to turn off an inductive load. Also, CR_2 relieves SCR's from free-wheeling duty. See Sec. 8.5.

Chart 8.1 (cont.)

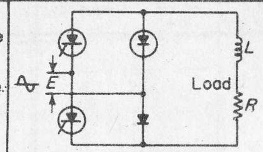
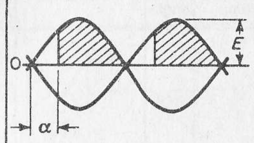
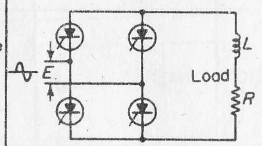
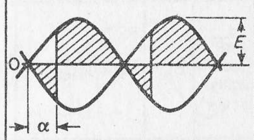
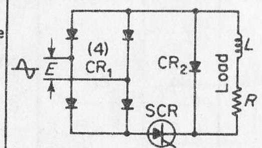
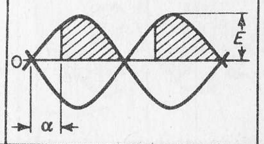
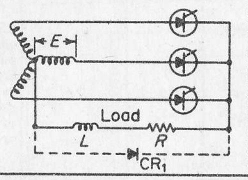
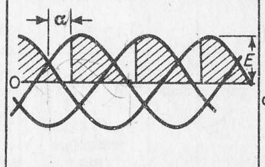
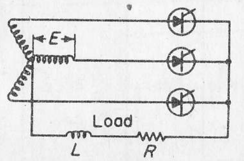
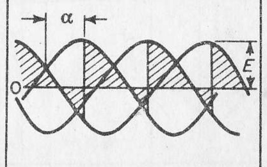
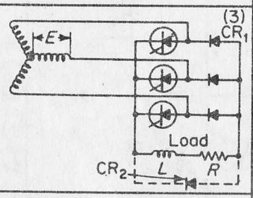
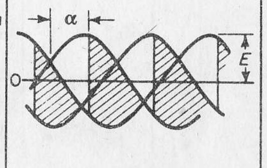
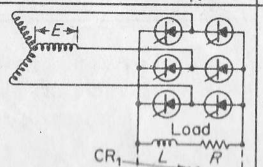
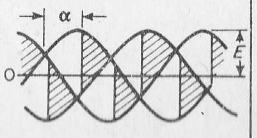
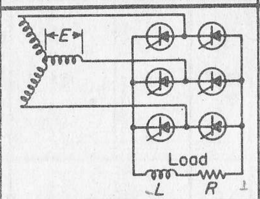
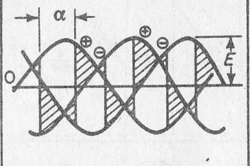
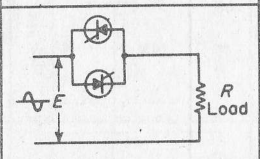
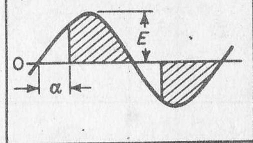
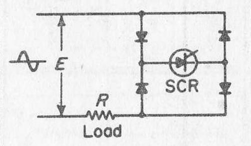
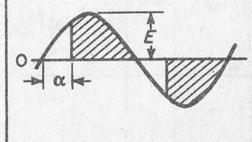
Circuit (a) Name	Circuit (b) Connections	(c) Load voltage waveforms	(d) Peak forward voltage on SCR	Peak reverse voltage (e) On SCR	Peak reverse voltage (f) On diode	(g) Max. load voltage ($\alpha = 0$) E_D = average d-c value E_a = RMS a-c value
(7) Single-phase bridge with 2 SCR's on common a-c line. Resistive or inductive load			E	E	E	$E_D = \frac{2E}{\pi}$
(8) Single-phase bridge with 4 SCR's and inductive load			E	E	—	$E_D = \frac{2E}{\pi}$
(9) Single-phase bridge with single SCR in d-c circuit. Resistive or inductive load			E	0	E (CR_1 and CR_2)	$E_D = \frac{2E}{\pi}$
(10) Three-phase half-wave with resistive load, or inductive load with free-wheeling rectifier			E (possibly $\sqrt{3}\,E$ if load open and if SCR's have high reverse currents	$\sqrt{3}\,E$	E	$E_D = \frac{3\sqrt{3}\,E}{2\pi}$
(11) Three-phase half-wave with inductive load (no free-wheeling rectifier)			$\sqrt{3}\,E$	$\sqrt{3}\,E$	—	$E_D = \frac{3\sqrt{3}\,E}{2\pi}$
(12) Three-phase bridge with 3 SCR's. Resistive load, or inductive load with free-wheeling rectifier			$\sqrt{3}\,E$	$\sqrt{3}\,E$	$\sqrt{3}\,E$	$E_D = \frac{3\sqrt{3}\,E}{\pi}$
(13) Three-phase bridge with 6 SCR's. Resistive load, or inductive load with free-wheeling rectifier			$\sqrt{3}\,E$ (1.5E if SCR's shunted by resistance)	$\sqrt{3}\,E$	$\sqrt{3}\,E$	$E_D = \frac{3\sqrt{3}\,E}{\pi}$

Chart 8.1 (cont.)

(h) Load voltage vs trigger delay angle α	(j) Trigger angle range full ON to full OFF	Max. steady-state current in SCR (k) Average amp	Max. steady-state current in SCR (l) Cond. angle	Max. steady-state current in diode rectifier (m) Average amp	Max. steady-state current in diode rectifier (n) Cond. angle for max. current	(p) Ability to pumpback inductive load energy to supply line	(q) Fundamental frequency of load voltage (f = supply frequency)	(r) Notes and comments
$E_D = \frac{E}{\pi}(1 + \cos\alpha)$	180°	$\frac{E}{\pi R}$	180°	$\frac{E}{\pi R}$	180°	No	$2f$	Diode rectifiers act as free-wheeling path, conduct ($\pi + \alpha$) degrees with inductive load.
$E_D = \frac{2E}{\pi}\cos\alpha$ (assuming continuous current in load)	180°	$\frac{E}{\pi R}$	180°	—	—	Yes	$2f$	With resistive load operation is same as circuit (7).
$E_D = \frac{E}{\pi}(1 + \cos\alpha)$	180°	$\frac{2E}{\pi R}$	360°	$CR_1 = \frac{E}{\pi R}$ $CR_2 = 0.16\left(\frac{2E}{\pi R}\right)$	180° 148°	No	$2f$	CR_2 necessary when load is not purely resistive. Frequency limited by recovery characteristics of rectifiers and SCR's.
$E_D = \frac{3\sqrt{3}\,E}{2\pi}\cos\alpha$ ($0 < \alpha < 30°$) $E_D = \frac{3E}{2\pi}[1 + \cos(\alpha + 30°)]$ ($30° < \alpha < 150°$)	150°	$\frac{\sqrt{3}\,E}{2\pi R}$	120°	$0.16\left(\frac{3\sqrt{3}\,E}{2\pi R}\right)$	134°	No	$3f$	
$E_D = \frac{3\sqrt{3}\,E}{2\pi}\cos\alpha$ (assuming continuous current in load)	150°	$\frac{\sqrt{3}\,E}{2\pi R}$	120°	—	—	Yes	$3f$	
$E_D = \frac{3\sqrt{3}\,E}{2\pi}(1 + \cos\alpha)$	180°	$\frac{\sqrt{3}\,E}{\pi R}$	120°	$CR_1 = \frac{\sqrt{3}\,E}{\pi R}$ $CR_2 = 0.14\left(\frac{3\sqrt{3}\,E}{\pi R}\right)$	120° 132°	No	$3f$	Without CR_2, SCR's may be unable to turn off an inductive load. Also, CR_2 relieves SCR's from free-wheeling duty.
$E_D = \frac{3\sqrt{3}\,E}{\pi}\cos\alpha$ ($0 < \alpha < 60°$) $E_D = \frac{3\sqrt{3}\,E}{\pi}\left(1 + \frac{\cos\alpha}{2} - \frac{\sqrt{3}}{2}\sin\alpha\right)$	120°	$\frac{\sqrt{3}\,E}{\pi R}$	120°	$0.056\left(\frac{3\sqrt{3}\,E}{\pi R}\right)$	212°	No	$6f$	SCR's require two gate signals 60° apart each cycle, alternately a gate signal duration > 60°

Chart 8.1 (cont.)

Circuit (a) Name	Circuit (b) Connections	(c) Load voltage waveforms	(d) Peak forward voltage on SCR	Peak reverse voltage (e) On SCR	Peak reverse voltage (f) On diode	(g) Max. load voltage ($\alpha = 0$) E_D = average d-c value; E_a = RMS a-c value
(14) Three-phase bridge with 6 SCR's with inductive load			$\sqrt{3}\,E$ (1.5E if SCR's shunted by resistance)	$\sqrt{3}\,E$	–	$E_D = \frac{3\sqrt{3}\,E}{\pi}$
(15) Inverse parallel SCR's with resistive load			E	E	–	$E_a = \frac{E}{\sqrt{2}}$
(16) SCR inside bridge with a-c resistive load			E	0	E	$E_a = \frac{E}{\sqrt{2}}$

During the positive half-cycle of the supply voltage, the SCR anode is positive with respect to its cathode, and the gate can exert control over the SCR conduction characteristics as described in detail in Sec. 5.2. Until the gate is triggered by a proper positive signal from the trigger circuit, the SCR blocks the flow of load current in the forward direction. At some arbitrary delay angle α, a positive trigger signal is applied between gate and cathode which initiates SCR current conduction. Immediately the full supply voltage, minus approximately one volt drop across the SCR, is applied to the load. With a zero reactance source and a purely resistive load, the current waveform after the SCR is triggered will be identical to the applied voltage wave, and of a magnitude dependent on the amplitude of the voltage and the value of load resistance R. As shown in Fig. 8.1(b), load current will flow until it is commutated by reversal of the supply voltage at $\omega t = \pi$. By controlling the trigger delay angle α with respect to the supply voltage by such means as described in Chap. 5 and later in this chapter, we may vary the phase relationship of the start of current flow to the supply voltage and control the load current from a maximum value down to zero—hence the term *phase control.*

Chart 8.1 (cont.)

(h) Load voltage vs trigger delay angle α	(j) Trigger angle range full ON to full OFF	Max. steady-state current in SCR (k) Average amp	Max. steady-state current in SCR (l) Cond. angle	Max. steady-state current in diode rectifier (m) Average amp	Max. steady-state current in diode rectifier (n) Cond. angle for max. current	(p) Ability to pumpback inductive load energy to supply line	(q) Fundamental frequency of load voltage (f = supply frequency)	(r) Notes and comments
$E_D = \frac{3\sqrt{3}\,E}{\pi}\cos\alpha$ (assuming continuous current in load	120°	$\frac{\sqrt{3}\,E}{\pi R}$	120°	—	—	Yes	$6f$	SCR's require two gate signals 60° apart each cycle, alternately a gate signal duration > 60°.
$E_a = \frac{E}{\sqrt{2\pi}}(\pi - \alpha + \frac{1}{2}\sin 2\alpha)^{1/2}$	180°	$\frac{E_a}{2.2R}$ or $\frac{E}{\pi R}$	180°	—	—	—	f	With inductive load, load voltage and current depend on $\omega L/R$ as well as R and α.
$E_a = \frac{E}{\sqrt{2\pi}}(\pi - \alpha + \frac{1}{2}\sin 2\alpha)^{1/2}$	180°	$\frac{E_a}{1.1R}$ or $\frac{2E}{\pi R}$	360°	$\frac{E_a}{2.2R}$ or $\frac{E}{\pi R}$	180°	—	f	Inductance in d-c circuit must be minimum. Frequency limit determined by recovery characteristics of rectifiers and SCR's. With inductive load, load voltage and current depend on $\omega L/R$ as well as R and α.

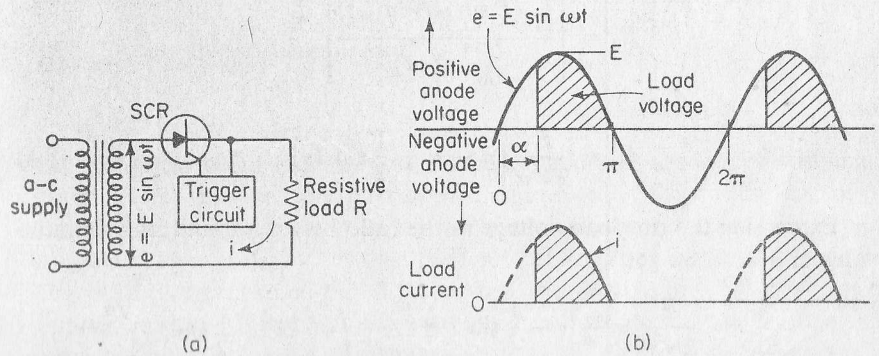


Fig. 8.1 Half-wave phase-controlled SCR with resistive load: (a) circuit; (b) waveforms.