CHAPTER 13
RECTIFIERS AND FILTERS

BASIC RECTIFIER CHARACTERISTICS

All rectifiers exhibit relatively low resistance (forward resistance) when the anode is positive with respect to its cathode, and high resistance (reverse resistance—typically at least 10^3 times the forward resistance) when the anode is negative with respect to the cathode. Since semiconductors have replaced electron tubes in most rectifier applications, the discussion of electron-tube rectifiers is brief and most of the material deals with semiconductor rectifiers.

COMPARISON OF RECTIFIER TYPES

Electron-tube rectifiers have one advantage over semiconductors. The reverse resistance of a tube rectifier is essentially infinite (neglecting insulation leakage, etc.) while that of a semiconductor is finite (although considerably higher than the forward resistance). Semiconductors have the advantages of requiring no filament power and, for a given power rating, are much smaller in size. For many high-power applications, semiconductor rectifiers must be mounted on heat sinks. However, the combination of rectifier and heat sink generally occupies less space than an equivalent electron-tube device.

Table 1 compares the characteristics of silicon, germanium, selenium, and copper-oxide semiconductor rectifiers.

TYPICAL RECTIFIER CIRCUITS

Table 2 shows seven of the most commonly used power-rectifier circuits and general design information for each type. Their advantages, disadvantages, and common applications follow.

Single-Phase Half-Wave Rectifier: Since only half of the input wave is used, the efficiency is low and the regulation is relatively poor. Capacitors are commonly used in half-wave circuits to increase the output voltage and decrease the ripple. The output voltage and degree of filtering are determined by the value of capacity used in relation to the load current. Transformer design is complicated, and the unidirectional secondary current flow causes core saturation and poor regulation. Most half-wave circuits operate either directly from ac lines, or at a high voltage with a relatively low current.

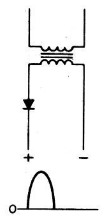
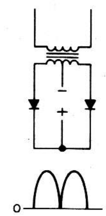
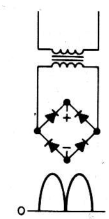
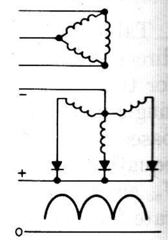
Single-Phase Full-Wave Center-Tap Rectifier: The efficiency is good but the transformer ac voltage is approximately 2.2 times the dc output voltage. The circuit requires a larger transformer than an equivalent bridge rectifier, with the added complication of a center tap. Each arm of the center-tap circuit must block the full terminal voltage of the transformer. Because of this, center-tap connections are economical only in voltage ranges where not more than one rectifier per arm is required. If series units must be used to obtain the required output voltage, a bridge circuit is preferable.

Single-Phase Full-Wave Bridge Rectifier: If single-phase full-wave output is required, a bridge circuit is commonly used. Efficiency is good and transformer design is easy. Filtering is simplified because the ripple frequency is twice the input frequency.

Three-Phase Wye (or Star) Half-Wave Rectifier: Commonly used if dc output-voltage requirements are relatively low and current requirements are moderately large. The dc output voltage is approximately equal to the phase voltage. However, each of the three arms must block the line-to-line voltage, which is approximately 2.5 times the phase voltage. For this reason, it is desirable to use a 3-phase half-wave connection only where one series unit per arm will provide the required dc output. The transformer design and utilization are somewhat complicated because there is a tendency to saturate the core with unidirectional current flow in each winding.

Three-Phase Full-Wave Bridge Rectifier: Commonly used if high dc power is required and if efficiency must be considered. The ripple component in the load is 4.2% at a frequency 6 times the input frequency, so additional filtering is required in most applications. The dc output voltage is approximately 25% higher than the phase voltage, and each arm must block only the phase voltage. Transformer utilization is good.

TABLE 2—RECTIFIER CIRCUIT CHART. THE DATA ASSUME ZERO FORWARD DROP AND ZERO

Type of Circuit→		Single-Phase Half Wave	Single-Phase Center Tap	Single-Phase Bridge	Three-Phase Star (Wye)
Primary→ Secondary→ One Cycle Wave of Rectifier Output Voltage (No Overlap)					
Number of rectifier elements	=	1	2	4	3
RMS dc volts output	=	1.57	1.11	1.11	1.02
Peak dc volts output	=	3.14	1.57	1.57	1.21
Peak reverse volts per rectifier element	=	3.14	3.14	1.57	2.09
	=	1.41	2.82	1.41	2.45
	=	1.41	1.41	1.41	1.41
Average dc output current	=	1.00	1.00	1.00	1.00
Average dc output current per rectifier element	=	1.00	0.500	0.500	0.333
RMS current per rectifier element:					
Resistive load	=	1.57	0.785	0.785	0.587
Inductive load	=	—	0.707	0.707	0.578
Peak current per rectifier element:					
Resistive load	=	3.14	1.57	1.57	1.21
Inductive load	=	—	1.00	1.00	1.00
Ratio of peak to average current per element:					
Resistive load	=	3.14	3.14	3.14	3.63
Inductive load	=	—	2.00	2.00	3.00
% Ripple (rms of ripple/ average output voltage)	=	121%	48%	48%	18.3%
Ripple frequency	=	1	2	2	3
		Resistive Load	Inductive Load or Large Choke Input Filter		
Transformer secondary rms volts per leg	=	2.22	1.11 (to center-tap)	1.11 (total)	0.855 (to neutral)
Transformer secondary rms volts line-to-line	=	2.22	2.22	1.11	1.48
Secondary line current	=	1.57	0.707	1.00	0.578
Transformer secondary volt-amperes	=	3.49	1.57	1.11	1.48
Transformer primary rms amperes per leg	=	1.57	1.00	1.00	0.471
Transformer primary volt-amperes	=	3.49	1.11	1.11	1.21
Average of primary and secondary volt-amperes	=	3.49	1.34	1.11	1.35
Primary line current	=	1.57	1.00	1.00	0.817
Line power factor	=	—	0.900	0.900	0.826

RECTIFIERS AN

REVERSE CURRENT

Three-Phase Brid

6
1.00
1.05
1.05
2.45
1.41
1.00
0.333
0.579
0.578
1.05
1.00
3.15
3.00
4.2%
6
Inductive Lo
0.428 (to neutral)
0.740
0.816
1.05
0.816
1.05
1.05
1.41
0.955