Technical Note #4

Rectifiers and Power Factor

For power supplies above a few kilowatts, the most common type of AC/DC converter is the three-phase full wave bridge rectifier, otherwise known as a six-pulse rectifier. This topology offers the most robustness and reliabilbily when compared to other topologies, high frequency switch-mode, for instance.

However, all AC/DC rectifiers suffer from two primary drawbacks, low power factor and line harmonics. This paper will concentrate on the power factor issue. It is interesting to note that although 12, 18, or 24 pulse rectifiers are available, these units behave almost identically when it comes to power factor. Their primary advantage is the reduction of line harmonics.

Power Factor Defined

Power factor can be defined as:

$$PowerFactor = \frac{\mathrm{Re}\,alPower}{ApparentPower}$$

A true resistive load will have a power factor of one. In this case, the real power is equal to the apparent power. Most real-world loads however, have inductance and the current waveform lags behind the voltage waveform. This affect causes only part of the circuit's KVA to produce real watts. The remainder of the circuit's KVA is simply circulating into, then out of, the circuit's inductance. This circulating current causes all the powering equipment to pass this current, and get warm, but produces no real power in the load. Power companies recognize this waste and charge penalties for lower power factor loads.

If the load power factor is rather constant, then compensation capacitors can be added to the circuit. This causes a current "lead" which compensates for the inductance's lag. Even for varying loads, variable capacitor banks are available which can monitor and continually compensate these loads.

A fixed output, non-regulated diode-based rectifier has a theoretical power factor of 0.95. This type of unit is seldom used, because it is not regulated. Regulation is achieved by replacing the diodes with SCRs. By controlling the turn-on point (or phase delay angle) of the SCRs, an adjustable output can be produced. When the SCRs are phased on fully, they would resemble diodes in function. By phasing-back, the delay angle the output is decreased towards zero. In most practical circuits, and in all Alpha Scientific power supplies, there is inductance in the output circuit. This inductance is directly attributed to the load (an electromagnet, for example) or can be because of the filtering choke (used for ripple reduction). The effect of the inductance is to increase each SCRs conduction period to its maximum 1/3 of a line cycle or 120°. If the load current can be thought of as continuous (ripple free) DC, then the SCR currents will be switched square waves, rising from 0 to full current, staying constant for 1/3 of a cycle, then going off for 2/3 of a cycle. Each pair of SCRs takes its turn at delivering the full current. A detailed analysis of this will show that during the SCR conduction period, the input voltage's may be either positive or negative. If the SCRs conduction period coincides with the positive voltage part of the sine wave, then the flow of power is from the line to the load (rectification). If the conduction period is during a negative portion of the input's sine wave then the flow of power is from the load to the power line (inversion). During all practical operating conditions, the power supply will both rectify and invert during each line cycle. The amount of either depending almost exclusively upon the phase delay angle.

Since operation at full phase-on will result in the best power factor. It would be best to design a power supply to always operate at this point. However, because the power supply must operate even if the incoming power line is 10% low or the loads resistance were to vary, a margin must be included to allow for this. Typically, at nominal values of inputs and outputs, a power supply might operate at 0.9 power factor.

Input Current

One clear illustration, showing the result of phasing back is to assume that a power supply is required to deliver exactly 1/2 of its full current. Under this condition, the voltage of the load would also be 1/2 of maximum. The power to the load would be 1/2 times 1/2 or 1/4 of the total. However, in order to deliver 1/2 the output current, 1/2 of the input current is required. However, 1/2 of the input current at the same input voltage is only 1/2 of the input KVA. Clearly 1/2 of the input KVA to produce 1/4 of the output watts of a power factor of 0.5 (actually a little less)

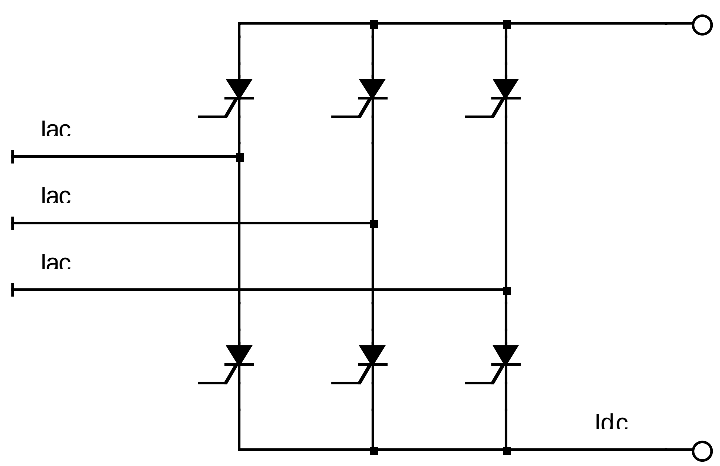
From the above illustration, it becomes evident that a rectifier can really be considered as a "current" transformer. The input current has a direct relationship to the output current. The output voltage and power do not enter this equation. If a load were short-circuited, it would still require the same input current as any other load. Into a short circuit, there will be no output power, because the voltage is zero. Power factor is therefore zero. As the load resistance increases, the output power increases, the power factor increases, yet the input current remains the same. This statement is mostly true and neglects several relatively small effects such as transformer energizing currents and internal transformer impedances.

The following chart shows the relationship between input and output values. The values shown are only approximate.

Output Current (%)	Output Power (%)	Input KVA	Power Factor
*110	121	110	0.95
100	100	100	0.90
90	81	90	0.81
80	64	80	0.72
70	49	70	0.63
60	36	60	0.54
50	25	50	0.45
40	16	40	0.36
30	9	30	0.27
20	4	20	0.18
10	1	10	0.09

* The 110% row is intended only to illustrate the best power factor achievable at the point of full phase-on (approximately 10-20% overcurrent)

It may be helpful to review the following equations and figures, remembering that they are true for any phase delay angle.

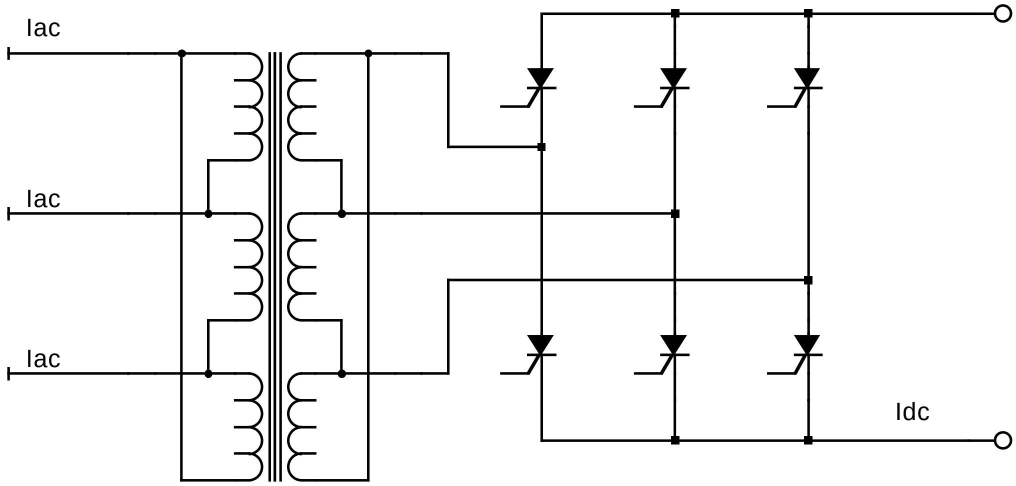


$$Iac = \sqrt{\frac{2}{3}} Idc$$

or

$$Iac = 0.816 \bullet Idc$$

A real power supply would use a transformer to change the voltage, current ratios to match the load requirements. Therefore, the input current is now the same as above only modified by the transformer's turn ratio.



In conclusion, the power factor of a rectifier is variable over a wide range as the unit's output is varied. The maximum KVA occurs at full output power. As the output is decreased, the real power falls off as a function of the square of the current, yet the input KVA decreases linearly. This results in a power factor that can be estimated simply by knowing the output current of the power supply.