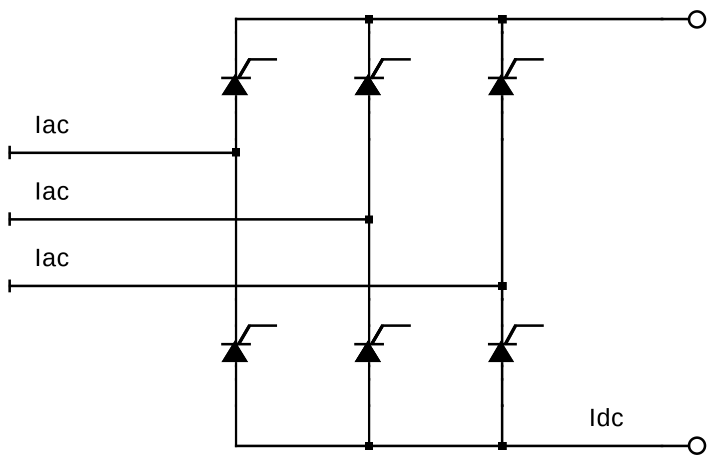
Technical Note #5

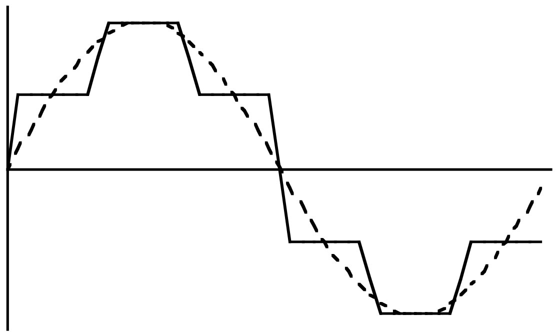
Simple Yet Effective Method for Reducing Harmonics in a Facility

The common three-phase bridge rectifier or 6-pulse rectifier is the workhorse of many large facilities requiring DC power. Rectifiers and Thyristor-Controlled Power Supplies are almost always the most electrically efficient, cost effective, reliable source of DC power available. This basic circuit is shown below.

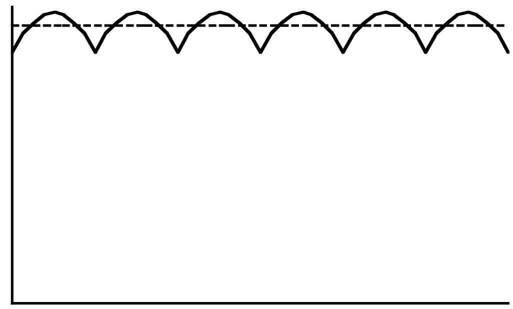


Input and Output Characteristics

During one complete line cycle, the DC output current is produced by the sequential conduction of each rectifier. Each rectifier conducts for one third of the line cycle or 120°. Therefore, during each line cycle the top "positive" rectifiers will each take their turn providing the output current, 1/3 + 1/3 + 1/3. The bottom "negative" rectifiers likewise conduct 120° each, yet their conduction is skewed 60° ahead of the positive rectifiers. The net effect is that the output current is sequenced though 6 conducting pairs of rectifiers during each line cycle. The effects of these 6 "pulses" can be seen in both the input and the output waveforms, shown below. Notice that the ideal waveshape, in each case is shown as a dotted line.



Input Waveform



Output Waveform

Depending upon the situation, the pulse, or ripple effect on the **output** waveform may have little consequence. In other cases, the ripple can be filtered to lower levels using passive or active components. Because the desired output is DC and the ripple frequency is 6 times the line frequency, (the 6^{th} harmonic), a low-pass filter has the proper characteristics. Actually by using combinations of both passive and active filters, ripple amplitudes can be reduced to very, very, low levels.

The 6-pulse conduction of the rectifiers is also apparent in the **input** waveform. An ideal input wave would like to be completely sinusoidal. The waveform of the rectifiers however, contains many harmonics. Analysis of the input, however show that the lowest harmonics is not the 6^{th}. Even number harmonics, such as the 6^{th} cannot exist in any waveform that is symmetrical in its positive and negative half cycles. The predominant harmonic is the 5^{th} and the 7^{th}. Following is a table showing the theoretical amplitudes of various harmonics.

Harmonic	6-pulse	12-pulse	18-pulse	24-pulse
5	.200			
7	.143			
11	.091	.091		
13	.077	.077		
17	.059		.059	
19	.053		.053	
23	.043	.043		.043
25	.040	.040		.040
from IEEE C57.18.10 - Table 11				

These input harmonics are much more difficult to filter than output harmonics. Although a low pass filter might be used, it becomes difficult to design a filter that attenuates the harmonics, while still passing the fundamental line frequency. The better method is to use a notch filter, rather than a low-pass filter. Yet, even notch filters when used in rectifier applications, are sometime difficult to implement. The filter relies on resonating components such as inductors and capacitors to perform its function. In a facility wide installation, there are many unknowns (system impedances, resonances, etc.) that affect the proper tuning of these filters.

Mitigating the Harmonics

In any rectifier, it always produces better input and output characteristics by increasing the pulse number. A facility full of 12, 18 or 24-pulse rectifiers will have lower harmonics than one full of 6-pulse units. Referring to the above table, it is apparent that higher pulse numbers directly translates in to elimination of lower order harmonics.

When looking at 12,18,or 24 pulse rectifiers, schematically, it becomes readily apparent that the higher pulse numbers are achieved by combining 6 pulse rectifiers so that their inputs are skewed from each other. By skewing multiple 6-pulse rectifiers, relative to one another, the 6 pulses become intertwined. This is most commonly done using phase shifting transformers. Two transformers, identical in all other regards, yet with delta windings or wye windings, exhibit a 30° phase shift. Be means of even more winding configurations, almost ant phase shift can be achieved. A 24 -pulse rectifier, for example, uses 4 transformers, evenly shifted. Compared with a 6 -pulse converter, there is a multi-fold improvement of the input and output waveforms. The units become more like an ideal AC-DC converter!

While the input and the output characteristics improve with increasing pulse numbers, so does the circuit complexity. The component count goes up. Any statistical analysis of system reliability dictates that increased component count translates to lower overall reliability.

Again, in many applications the **output** characteristic of a 6-pulse rectifier is adequate. The improvement gained by higher pulse numbers while good, is not the driving force behind desiring this increase, it is because of the beneficial **input** characteristics. Knowing this, many facilities can use multiple 6-pulse units, each with its input phase angle offset from neighboring units. By dividing the total rectifier load into 4 different types, a simulated 24-pulse load can be achieved. Obviously, for complete simulation of 24 pulses, the input currents in each "phase offset" section must be equal. This will probably never be truly achieved. However, the important point to consider is:

> Using phase shifted power supplies, the combined total input harmonics will ALWAYS be lower than with the same number of power supplies, all phased the same.

The combined higher pulse number will result in lower harmonics in the power line. It is understood that the individual power supplies will each exhibit 6-pulse input performance, the resulting lower order harmonics (5^{th}, 7^{th}) will circulate between it and its phase-offset neighbors. Careful design of the AC feeder layouts will try to group the appropriately offset units in the same electrical "vicinity". Further "upstream", electrically, in the facility there is an overall reduction in harmonics.

Conclusion

In many applications, 6-pulse rectifiers are adequate for their output characteristics. Specifying higher pulse number power supplies does improve the input characteristics, but at the cost of added circuit complexity. In facilities the use many similarly rated units, the combined facility power system can see the same beneficial effects by specifying 6 pulse units with their input's phase shifted from one another. This combines the advantages of lower cost, 6-pulse units with the advantages of lower harmonics in the facility's AC power system.