ELECTRICAL DIVERSIONS AND AMUSEMENTS

Six-pulse rectifiers, five centuries ago

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Almost all electronic devices – computers, variable frequency drives, telephones – operate from DC. But, as it has turned out for both historical and technical reasons, we distribute electric power as AC. Especially in large loads, we generally use rectifiers and bulk capacitors for the necessary conversion from AC to DC. And that circuit topology always draws current in pulses, right near the peak of the voltage waveform, just when the AC voltage instantaneously exceeds the DC voltage on the bulk capacitor causing the rectifiers to conduct.
It would be nice if we could pull current from the AC mains in a smooth, non-pulsed sine wave – after all, that's how incandescent lights and heaters draw current – but we're stuck with this pulsed current that doesn't look anything like a sine wave. In fact, that is one of the main sources of harmonic currents on the grid. (Fig. 1)

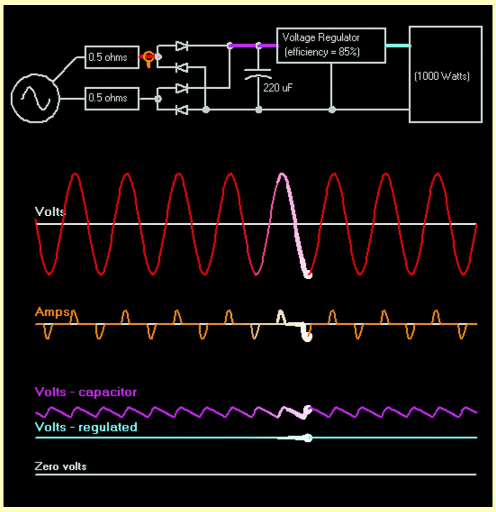

Fig. 1. A modern single-phase rectifier-capacitor supply. The current, shown in orange, is a pulse at the peak of each voltage waveform. Simulated by the Power Quality Teaching Toy program, available free at http://www.PowerStandards.com/PQTeachingToy

This is not a new problem. Early water wheels were initially used for grinding grain, and grinding with a grist mill is a nice, steady, continuous load, just like a heater or a light bulb. But then, sometime around the 12th century, clever craftsmen realized that, by adding a trip toggle on the shaft and a heavy pivoting hammer, they could reduce their labor, and still use the water wheel to power their bellows. What a great idea! Except that the pulsed load is inefficient. It requires a large pulse of energy during a small fraction of the wheel's rotation, and no energy at all during the rest of the rotation, so you're forced to over-size your water wheel. (Sounds like a single-phase rectifier load, right?) (Fig. 2)

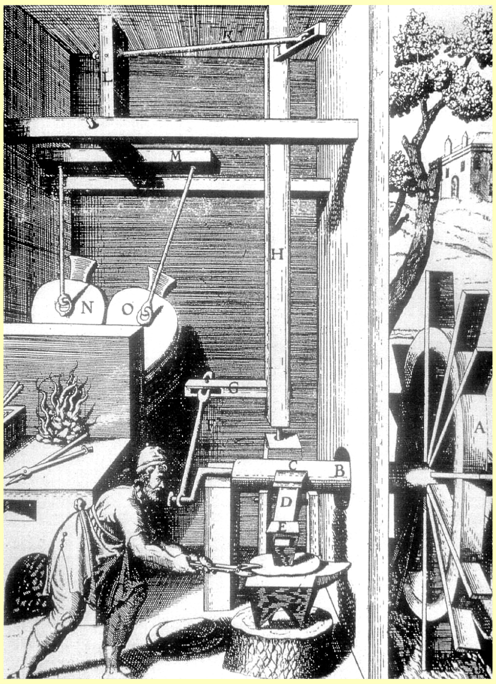

Fig. 2. An early single-pulse water-wheel load. The trip toggle C on the shaft B lifts, and suddenly drops, the hammer E. But, like a single-phase rectifier supply, the hammer only extracts energy during a short part of each cycle.

A common solution, in modern electronics, is to use a six-pulse rectifier. Instead of two pulses of current each fundamental cycle, this three-phase configuration draws six pulses, evenly spread around the cycle. (If you want, you can use a phase-shift transformer to create a 12-pulse rectifier which comes ever closer to the ideal sine wave current.)
New idea? Not at all. (Fig. 3, see next page)

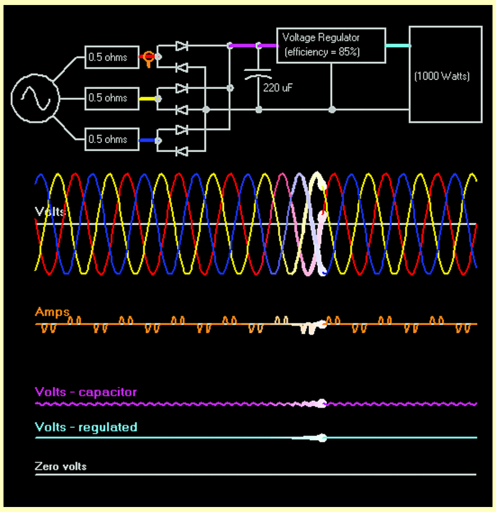

Fig. 3. In a six-pulse rectifier with the same load, there are several pulses each cycle, with lower amplitudes, so the harmonic currents are reduced. By creating 6-phase power with a phase-shifting transformer, this idea can be extended to a twelve-pulse rectifier. Simulated by the Power Quality Teaching Toy program, available free at http://www.PowerStandards.com/PQTeachingToy

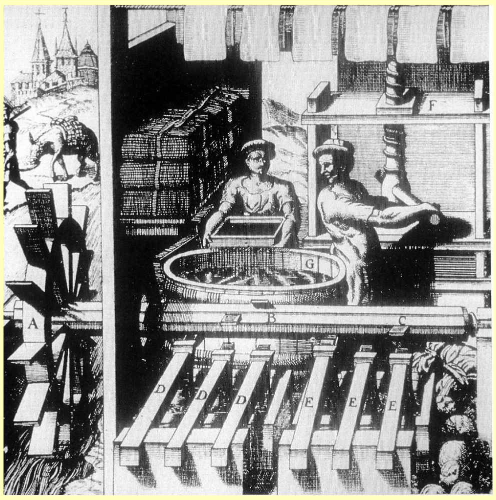

Fig. 4. There are very few new ideas. Here's a 6-pulse rectifier from the 1400's – the hammers are pounding fibers to make paper. See the text for a list of errors in this engraving.

Here's a 6-pulse rectifier from the 1400's. The trip hammers 'D' and 'E' pound paper pulp. They are operated by toggles 'C', spaced in phase around shaft 'B'. And if that's not a 6-pulse rectifier, I don't know what is! (Fig. 4)

Like many old etchings, the drawing communicates the basic idea correctly, but is full of interesting errors. There are 6 toggles and hammers, but the number of sides on the shaft is not an integral multiple of 6; the mule is hunchback rather than swayback (but maybe mules were like this back then); all three men are looking over their shoulders, which I suspect is an artistic convention; the blocking plate at 'F' should be on the underside of the crosspiece, not on top; and, most importantly, either the screw thread for the press is reversed, or the man is pulling the wrong way.

This last error might actually be the fault of the engraver. As anyone who has done any engraving knows, you have to etch a mirror image of the drawing. Hold this drawing up to a mirror, and the screw thread is correct.

So there are at least two lessons here: many modern technical problems, including mains harmonics currents, have ancient roots and solutions; and always, always check what the draftsman draws by looking at the final print.

Some engineers seem to find it a little discouraging that so many of our clever, modern, high-tech solutions were actually anticipated hundreds of years ago. Myself, I'm happy to think that the reverse may be true, too: some little solution that I come up with today, and publish, might be amusing and even a little useful to an engineer a few hundred years in the future. A pleasant thought, anyway.

In the next issue: Leonardo da Vinci's power factor correction capacitor.

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