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A Realistic, Insightful Demonstration of a Bridge Rectifier

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Abstract

A simple, insightful demonstration of a four-diode bridge rectifier is presented. Light emitting diodes (LEDs) replace the rectifier diodes. An ordinary function generator provides the voltage input and maintains the operation at safe voltage levels. Building the circuit and operating it is described. Setup and simple calibration and troubleshooting procedures are explained. Some notes on theory of operation supplement the presentation. The demonstration circuit is safe for classroom operation and is easily portable giving insight into rectifier operation by the dramatic effect of flashing lights.

Introduction

Single phase diode bridge rectifiers are a workhorse of power electronic energy conversion. A host of electronic systems draw energy through power supplies containing such rectifiers. These systems cover a range in size and purpose from simple plug-in converters to the switch mode power supplies that are a common element of most personal computers.

Learning and understanding their operation and design can be challenging. There are several textbooks that do an excellent job of explaining how these rectifiers operate.[1] Nonetheless, seeing such a circuit in operation often helps the student understand how it works. Complicated or unfamiliar instrumentation can slow the learning down, but a working circuit with simple visual impact can dramatically enhance understanding.

In this paper, a simple demonstration using a working rectifier helps introduce the circuit's operation to the student. The circuit is intended as introductory, with flashing lights to illustrate important points. The circuit is portable and construction is well within the capability of an undergraduate electrical engineering program, requiring just a small piece of circuit board and a simple function generator. Setup and troubleshooting requires no more instrumentation. The insight gained by its simple operation helps introduce students to the operation of switching rectifier circuits.

Circuit Construction

The topology for this circuit is that of the standard four-diode bridge rectifier as shown in Figure 1. The diodes are light-emitting diodes (LEDs) rather than rectifier diodes. Numbered diodes D_1, D_2, D_3, and D_4 are all the same color, for example, red. Output diodes D_x and D_y are a different color than the other four diodes, for example, green or yellow. Polarities are as shown in the diagram. The forward voltage drop of typical cheap LEDs is approximately 2.0 Volts at a rated forward current of 20 mA.

The input voltage source is a simple function generator, such as those available in most undergraduate electronics labs. For this demonstration, the function generator must be able to deliver about 10V peak and 20mA peak, sinusoidal and square wave functions, at frequencies from approximately ½ Hz up to 60 Hz. A quick calculation reveals that the load should be around 100 ohms. To gain a little more flexibility, a load resistance of 47 ohms, ¼ watt, was selected. This gives a margin for loading in the event that the function generator has only a 10V open circuit rating and a significant output impedance, as several common models do. For the demonstration, no frills function generators, such as Hewlett-Packard HP3311A and HP3312A have performed well. Of course, there are a host of other models and manufacturers of function generators that can deliver the appropriate voltage and current to this load.

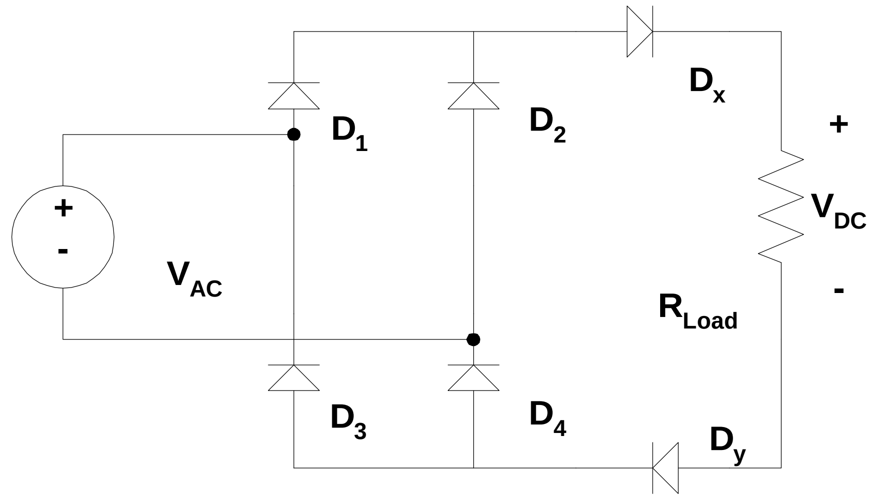

Figure 1. Circuit diagram of a single phase bridge rectifier.

The circuit can be built on a small piece of vector board or perf board. Arranging the LEDs in a configuration that the students are likely to recognize is important. In the demonstration at hand, the LEDs are arranged in a configuration that mimics the circuit diagram. Doing so makes the components easier to recognize. Students will quickly advance to investigating circuit operation rather than needlessly trying to recognize where components have been placed. Photographs of the demonstration circuit are shown in Figures 2 and 3.

Operation of the Circuit

This circuit is a functioning single phase bridge rectifier, not a mockup or simulation for demonstration purposes. It actually does full wave rectification, but in a fashion that readily reveals its behavior to the observer. It requires no more instrumentation than a simple function generator, making it quite portable.

Operation of the circuit is as follows: An alternating input voltage, when sufficiently positive, lights the LEDs D_1, D_x, D_y, and D_4, in the forward path, as shown in Figure 2. When the alternating input voltage reverses and becomes sufficiently negative, LEDs D_2, D_x, D_y, and D_3 glow, in the path shown in Figure 3. In each of these two cases, the current path is readily identifiable, from source, through the switching diode matrix, to the load, and return.

To enable the student to observe the circuit's switching behavior, the frequency of the input voltage should be set to a very low frequency, for example, ½ Hz. The numbered LEDs in the switching matrix will glow alternately at a speed that enables the observer easily to detect the pattern. The LEDs in series with the load will glow whenever the load receives current, which is at double the frequency of their numbered counterparts.

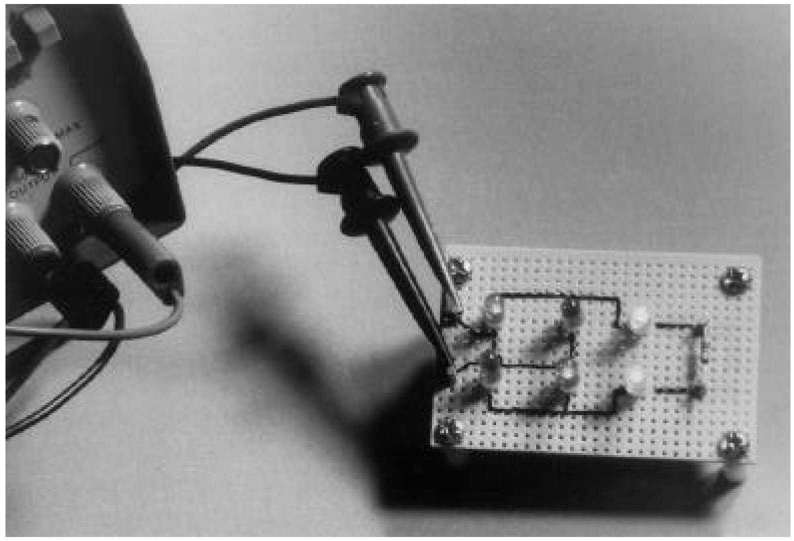

Figure 2. Operation during the positive half cycle

The small size of the circuit can be a disadvantage for large classes. However, the ease with which the operation can be grasped and the portability of the entire demonstration may mitigate this disadvantage. It rarely takes more than a few seconds for the student to realize the switching behavior that the circuit illustrates. This effect is particularly dramatic in classrooms fitted for video display from an overhead camera.

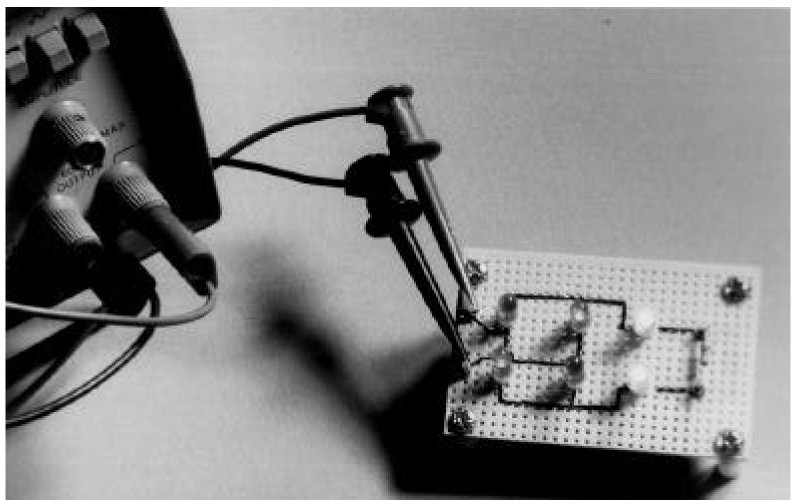

Figure 3. Operation during the negative half cycle

If the input voltage oscillates in a sinusoidal manner, the intensity of each LED appears to increase smoothly to a peak and then appears to decrease smoothly to darkness. If the input frequency is sufficiently low, this effect is quite noticeable. This gives opportunity for explanation of pulsating dc and the importance of filtering. Adding a filter to this circuit requires a capacitance in excess of 10,000 μF to retain a reasonable glow of the load LEDs. For this demonstration, so large a capacitor that may be impractical.

At frequencies sufficiently low to allow the students of observe the waxing and waning of LED intensity, as described in the previous paragraph, there is also an observable interval of darkness between pulses. This gives opportunity to explain the effect of forward voltage drop, which is unusually large in this circuit due to the nature of the LEDs and their quantity here.

As an alternative to a sinusoidal input voltage, a square wave may be applied. This causes abrupt switching between sets of LEDs and maintains a constant conduction in the two load LEDs. This situation is, of course, less realistic.

Setup, Calibration, and Troubleshooting

A quick operation check of the circuit is best performed at a frequency between 50 Hz and 100 kHz. Any common waveform, e.g., sine, square, triangle, etc., works well. Such frequencies are high enough to avoid noticeable flicker, but low enough to avoid noticeable waveform distortion caused by the speed of the LEDs as switching devices. At these frequencies, all LEDs should appear to glow steadily, giving verification that they all do operate. If all LEDs do not glow, the trouble is usually easy to identify from the pattern that remains because each branch of the circuit contains an LED.

If all components work properly, the next step is to eliminate any dc offset in the input voltage. Many function generators do have a dc offset option. When dc offset is present, one conducting pair of the numbered rectifying diodes (D_1D_4) appears to glow at a different intensity than the other pair (D_2D_3). Adjusting the function generator's dc offset knob to balance the intensity eliminates dc offset. If the input is a square wave at 50 Hz and below, dc offset also causes a noticeable flicker in the output load LEDs. Adjusting the function generator's dc offset knob to balance the intensity of the rectifier LEDs concurrently eliminates this flicker.

After verifying component operation and eliminating dc offset, as described in the preceding two paragraphs, the input frequency can be reduced to about ½ Hz. The LEDs should alternate slowly as desired. Selection of waveform, as described in the previous section, does influence behavior, as described in the preceding section.

Notes on Theory of Operation

A bridge rectifier of the topology shown in Figure 1 converts alternating current to pulsating direct current. It does so by directing current through diodes D_1 and D_4 when the input voltage is positive. Diodes D_2 and D_3 block during this time, which is ideally half of the period of the alternating input voltage. When the input voltage source becomes negative, diodes D_2 and D_3 conduct current to the load. Diodes D_1 and D_4 block current flow during this time.

Because the diodes have a forward voltage drop, current actually flows only when the input voltage exceeds the combined sum of the forward voltage drops of the appropriate pair of diodes (D_1D_4 or D_2D_3). In the circuit at hand, there are also two diodes (D_x and D_y) in series with the load, whose forward drops must also be overcome to permit current flow. This explains the "dead time", when all LEDs are dark, that appears between half-cycles when the input is a sinusoidal waveform, for example. Energy efficiency of this circuit is also a function of the number of diode voltage drops in series.

DC offset causes asymmetry in the positive and negative peak values of the input voltage. This problem gives several symptoms. Because each pair of rectifier diodes, D_1D_4 or D_2D_3, conducts during the respective positive or negative cycle of the input voltage only, an asymmetry appears as a difference in input voltage to these diode pairs. The load is identical for each pair, however. Consequently, an asymmetry in the current, and hence the light output, is the result. DC offset also causes consecutive peaks in the pulsating dc output voltage and current to alternate in intensity. In normal operation near 50 Hz, the output has only DC and perhaps even harmonics, depending on the input waveform, none of which typically give noticeable flicker. However, asymmetry causes components at 50 Hz (and odd harmonics) to appear. The 50 Hz component does yield a noticeable flicker.

Web-Based Animations of this Rectifier Circuit

An animation of this same circuit suitable for use on most web browsers is available at the following URL: http://www.ee.uidaho.edu/ee/power/hhess/diodes.gif. This circuit animates the same actions that the hardware described above does. It also shows an animation of the input and output voltage waveforms. A second animation of the same circuit, but with a large capacitor on the dc side of the diodes is available at the following URL: http://www.ee.uidaho.edu/ee/power/hhess/filter.gif. This second animation shows the voltage and current waveforms for both input and output. These waveforms are helpful in explaining power quality problems that such filtered power supplies cause. For further discussion of these power quality issues and some hardware demonstrations that illustrate these issues, see reference [2]

Conclusions

A realistic, insightful introductory demonstration of a four-diode bridge rectifier is described in this paper. The circuit is a functioning single phase rectifier in the ubiquitous bridge topology. LEDs replace rectifier diodes and operate at a reduced operating frequency to illustrate switching behavior. Voltage and heat dissipation are at safe levels for classroom work. The demonstration is quite portable, requiring only a small function generator and a circuit mounted on a small circuit board. Setup requires no additional instrumentation. Instructions for simple troubleshooting and methods to eliminate dc offset have been described in the paper.

Acknowledgements

Paul F. Barber from Citizens-Lehman Power Company in Boston, Massachusetts, recommended using LEDs in place of the numbered diodes. Greg Klemensrud from the University of Idaho built the circuit shown in Figures 2 and 3.

References:

[1] Hess, H.L., "Power Electronics Instruction: Topics, Curricula, and Trends," ASEE 1997 Annual Conference, Session 3233. This paper contains a list, exhaustive at the time of publication, of power electronics texts in print in North America.
[2] Hess, H.L., "Practical Classroom Demonstrations of Power Quality Issues," ASEE 1998 Annual Conference, Session 1333.

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Herb Hess received the PhD degree from the University of Wisconsin-Madison in 1993. He served on the faculty of the United States Military Academy from 1983-1988. In 1993, he joined the University of Idaho, where he is Assistant Professor of Electrical Engineering. His interests are in power electronic converters and electric machine drive systems.