What methods are used to generate alternating current in square, triangle, and sinusoidal waveforms and what are each's relative advantages?

Alternating Current Overview:

Alternating current changes polarity at regular time intervals; the period is the time it takes to return to its original state. The frequency is measured in hertz (oscillations per second) and is the reciprocal of the period. Alternating current can be produced in many waveforms, but there are three common forms: square, triangle and sinusoidal. In square wave AC the voltage is a constant positive value for half of the period and a constant negative value for the other half of the period. In the triangular waveform the voltage rises at a constant rate until it reaches its positive peak, and then falls at a constant rate until it reaches the negative peak and returns in the positive direction. In the sinusoidal waveform the voltage changes in a smooth continuous curve such as the sine and cosine curves [1]. Each waveform is produced differently and has different uses.

Generation:

Square wave AC is produced by the switching on and off of a direct current sources with half of the waveform at its positive value and the other half at the negative value. Schmitt, Clock, NAND Gate, and Ring Type are forms of square wave generators, some use capacitors with trigger action inverters like astable multivabrators [4]. Square wave can also be produced by the addition of an infinite number of sine waves. The harmonics allow sine waves to be added together with frequency increasing by an odd factor while the amplitude decreases by the same factor. The RMS voltage of a square wave is equal to the peak voltage, as well as the average voltage. This is because the voltage is constant for half of the waveform [3].

Triangular wave AC is produced by transistors and silicon controlled rectifiers SCRs. These components will modify regular sine waves and produce a chopped up modified wave form [3]. The triangular waveform can also be converted from square wave using an integrator which is a special circuit using an operational amplifier. The op amp has a capacitor connected in parallel to the feedback resistor so the op amp acts as a virtual ground. When the current flowing changes direction, the capacitor charges in the opposite polarity and the virtual ground allows the voltage to slowly dissipate in the capacitor thus creating a varying output [5]. The RMS Voltage of a triangle wave equal to 0.577 times the peak voltage or the peak voltage divided by the square root of three. The average voltage however is half of the peak voltage [3].

Sinusoidal wave AC is produced by a generator or an oscillator. Generators produce electricity with a conductor passing through a magnetic field. The induced voltage is collected with a brush on slip rings which are connected to the coil. When the wire loop rotates the field enclosed by the coil changes. Faraday's law explains how the change in magnetic field relative to an area also called flux causes an induced voltage called Electromotive Force. If the magnetic field, area of coil, speed of the rotation, or number of turns in the coil is increased the amplitude of the induced voltage increases. The angular frequency is given by the rate of change of the angle with respect to time, and the frequency in hertz is two pi times the angular frequency, so the speed of the rotation also changes frequency. Electric motors produce sine wave AC when they are running, the wire moving through the magnetic field generates a voltage in the opposite direction, so the current through the motor drops off as it reaches its syncronous

speed [2], [3]. Though this is how simple generators work, the question this raises is how do more complex generators work with DC excitation, three phase in delta vs wye, or slip rings feeding the field coils and the AC is collected from the stator on the outside?

Sine wave AC can also be produced by a simple inductive and capacitive oscillator. A fully charged capacitor is connected to an inductor. The capacitor discharges and builds a magnetic field in the inductor, when the capacitor is completely discharged the inductor starts to supply current to recharge the capacitor. The capacitor and inductor will store all of the energy, while the other one is completely discharged. This cycle will repeat almost indefinitely unless there is some small amount of resistance reducing the energy until the electricity is depleted [2], [3]. This poses the question if this technology can be be used to store alternating current?

Advantages:

A square waveform composed of many sine waves is used in the music industry to modify the harmonics of the output. By adjusting an individual frequency using a graphic equalizer on a high fidelity stereo, the user can modify the output waveform, thus adjusting the sound [3]. Square waves are used in digital timers and digital logic circuits on their input and output gates [4].

Triangular wave AC is used for firing thyristors, and tone generators. Because the rise and fall of the voltage is equal the sharp peak allows for a precise timing when it comes to firing the thyristors.[5] Where a larger average voltage is required the slope of the waveform is steeper [3].

Pure sine waves do not produce a noise from high frequency resonance. Non-sinusoidal waveforms can accidentally be produced by solid state electronic controls and can interfere with nearby electronics. Computers can produce very high frequencies that create resonance and noise elsewhere, whereas a true sine wave does not [3]. Sine waves can be produced by mechanical means, so no source electric voltage is required to generate electricity in this waveform. The electricity produced on the grid is alternating current in sinusoidal waveform because it is easy to generate using mechanical means like an alternator and transform the voltage for distribution [2].

Source Evaluation:

Most of the sources were very specific. Source [2] was very thorough in the description of how an alternator generates electricity using Faraday's law, thus raising many interesting questions. Source [3] was very descriptive, especially in the composition of sine waves into square waves. Source [4] and [5] was very descriptive in how to construct a waveform generator. These two sources raised more questions of how does the subcomponents work such as does the op amp work with the a high frequency and what is an astable multivabrator? It is difficult to find information on the advantages of different waveforms.

[1] K. Al-Olimat, *Electric Circuits Analysis*. Ronkonkoma, NY: Linus Learning, 2018.

[2] R. A. Serway, J. W. Jewett Jr. *Physics for Scientists and Engineers Technology Update*. Boston, MA: Cengage Learning, 2014.

[3] T. R. Kuphaldt, *Alternating Current (AC)*. Vol. II. [E-book] Available: All About Circuits.

[4] W. Storr "Waveform Generators," *electronics-tutorials.ws*, April 30th 2014 [Online]. Available: https://www.electronics-tutorials.ws/waveforms/generators.html. [Accessed Nov. 12, 2018].

[5] "Triangular Wave Generator," *circuitstoday.com*, Aug. 28, 2018. [Online]. Available: http://www.circuitstoday.com/triangular-wave-generator. [Accessed Nov. 12, 2018].