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Quantum Movement Theory of Alternating Current

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Abstract The most common way to evaluate the flow of electricity in a wire is via a load flow analysis, however; there is another way to view this behavior utilizing the Quantum Movement Theory proposed and discussed herein. This theory evaluates the movement of the charge carrier, the electron, within a conductor to register a specific amount of current in an alternating current system. Historically, the understanding of electricity flow on the electric grid has been based upon the previously popular direct current system of the 1880's. This research evaluates how electrons as both a particle and a wave move through conductors on the interconnected grid. Two mathematical applications comprising the; 1) volume of electrons moving in a conductor, and 2) the distance traveled by electrons in a conductor, are developed and explained within this article. The application of the equations and understandings contained herein can be applied to quantum mechanics within conductors on the modern electric grid comprised of alternating current equipment, as well as policy regulating such resources.

Keywords: *alternating current, electric, electron, energy movement, quantum movement theory, energy policy*

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1. Introduction

Electricity is a dependable and reliable part of modern society that allows individuals, businesses, and humanity to progress and maintain a certain quality of life. Electric research progressed leaps and bounds during the 19th century to form the basis for which we have built our understanding of electricity. Since the outcome of the well-known electricity debate in the United States during the 1880's between alternating current and direct currents systems, the majority of nations around the world have implemented alternating current electric grids. Through this time, we have gained an in-depth understanding of how to design and engineer these complex systems, but what is occurring within these critical components that deliver electricity to us every day? The phrases "flow of electrons" and "electron flow" are commonly used in reference to electricity movement for both AC and DC systems, but is that actually what is occurring? In order to properly accomplish this, we must first begin with the electron along with its properties and behavior.

There stands to be regulatory implications of this theory where claims are made based upon the "flow of electrons" or "electron flow", whereas that actually does not occur in alternating current systems. The Federal Energy Regulatory Commission (FERC) has used this very statement since the passage of the Federal Power Act in 1925 to support their claim that they have regulatory jurisdiction over all generation resources in the United States rather than the states or local electric utilities. This claim regarding electron flow has been cited over 300 times in various cases, briefings, or rulings to support FERC's assertion to have regulatory jurisdiction over these assets. If FERC were to have this authority granted by the United States Supreme Court, then it would increase interconnection timelines, direct and indirect interconnection evaluation costs, increased interstate commerce tax on assets that weren't previously eligible for them, and overall decrease the financial feasibility of distributed energy resource projects.

This article evaluates the quantum behavior of electrons that deliver electricity through conductors using alternating current. The goal is to develop two equations that can be used to calculate 1) the number of electrons moved given a specified current, and 2) the maximum distance moved by electrons due to the conductor specifications and current.

2. Electron Structure

Every element has a specific number of protons neutrons and electrons that give them their identity. Simply stated, atoms are structured with neutrons and protons held together inside the nucleus of an atom. The electrons are located outside the nucleus and move around it in what is commonly referred to as the electron cloud. Since protons are positively charged, this group of positively charged protons inside the nucleus of an atom keep the electrons bound inside the electron cloud. The negatively charged electrons are naturally pulled towards the center of an atom. This attractive force holding electrons and protons together is an electromagnetic force that keeps the atom held together.

Within atoms lies electron orbitals where the electrons are held at specific distances from the nucleus. Each level or orbital can hold a different number of electrons in it. This is commonly referred to as the Aufbau principal, and this can be utilized to determine the number of electrons in each orbital. One of the most commonly used conductors for distribution power lines is aluminum-steel reinforced conductor that relies primarily on the aluminum element for conducting electricity and the steel center is for strength (also referred to as a messenger cable). The element, aluminum or Al, has an atomic number of 13 which represents the number of protons in the nucleus of the atom, but also since it is a stable element it is the number of electrons surrounding the nucleus as well. [5] The 13 electrons have an electron configuration of $1s^2$ $2s^2$ $2p^6$ $3s^2$ $1p^1$ by using the Aufbau principal. [5] This can also be seen in Figure 1 where it indicates the direction of spin.

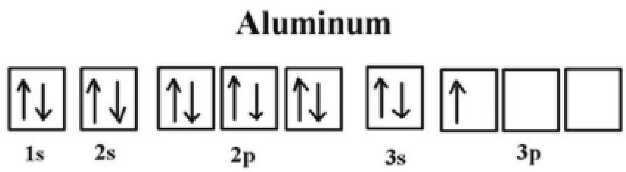

Figure 1. The Aufbau Principle illustrated for Aluminum with the number of electrons in each level and their spin up or down [2]

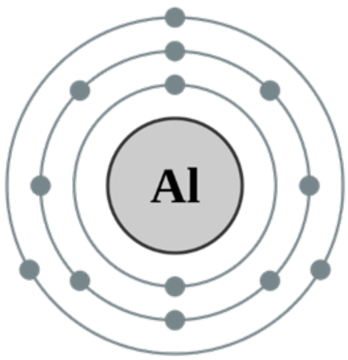

Figure 2. Illustration of the electrons in each orbital surrounding the proton and neutron center [4]

Each arrow represents an electron and ideally each electron will be matched with an electron of opposite spin before being left alone. Based upon the Aufbau electron configuration method in Figure 1, it can be seen that aluminum contains 3 electrons in its outer orbital which are comprised of 3s & 3p. Two electrons are indicated in the 3s orbital, and one electron is indicated in the 3p orbital. Figure 2 illustrates the electron location amongst the various orbital levels. Similar to Figure 1, the outermost orbital of aluminum in Figure 2 indicates that there are three electrons at that energy state.

The movement of these electrons are unique, and they have traits of both particles and waves. The particle understanding of electrons was well understood during the 20th Century, but the wave behavior of electrons was solidified during the 21st Century. Albert Einstein first recognized the particle-like behavior of photons in 1903, and Louis De Broglie first proposed the wave-like behavior of electrons in 1923. [5] Through this, De Broglie proposed that you can neither 100% know the magnitude or position of an electron because of the wave-like behavior of electrons. Through experimentation, he concluded that electron position is calculated through probabilities which is represented by a wave. In Figure 3, it shows the scattering of electrons into groups and the electron density is indicated by the wave at the bottom of the image. When predicting or determining the location of an electron it has a higher probability of being in a specified location at the peak of the wave. This understanding supports the electron orbital structure of the atom where electrons at different energy levels are held in different areas or zones where they're likely to be found. Another way to view the waves used in the probability of either determining the magnitude and position of electrons is seen in Figure 4.

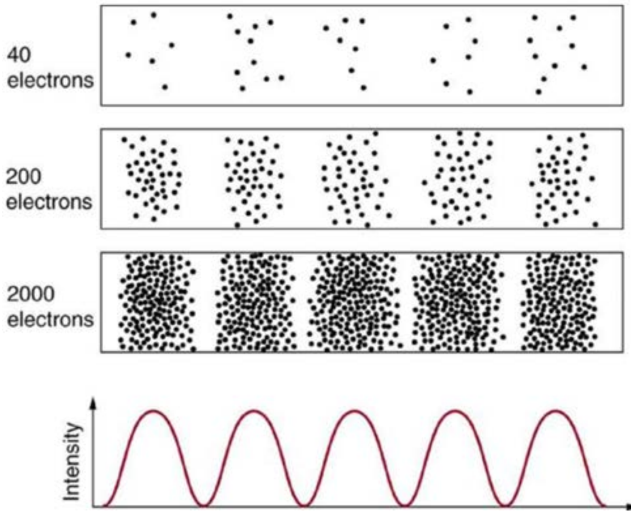

Figure 3. Illustration of electron distribution and the role that probability plays in predicting electron behavior [1]

This example illustrates that there is a more accurate prediction of the magnitude (momentum) due to the increased probability, whereas the position of the electron is less likely to be determined based upon the large wavelength. Schrödinger and Heisenberg applied mathematical probability to De Broglie's wavelike behavior of electrons. Heisenberg became known for his equation to calculate the uncertainty in one's prediction of magnitude or position of an electron, which is essentially the opposite of the probability of an electron to be in a certain location. This concept became known as the Heisenberg Uncertainty Principle.

Electrons are hard to predict their location, but that doesn't negate how their properties and behavior are critical to the transfer of electrical energy. What makes a conductor a good conductor of electricity is the ability of the atoms that make up the conductor to have electrons leave their valence orbital when a voltage is induced. Mankind has discovered that metallic objects typically have valence electrons with lower ionization energy levels, which means that at low voltages the electrons in the valence orbitals become free electrons. As these free electrons move from their "home" atom they weave in-between other atoms, can enter valence orbitals of other atoms, or exert force on other electrons. In this way, free electrons are passing energy to valence electrons and where they become valence electrons and continue the chain reaction. This interaction is where the transfer of energy occurs by free electrons passing energy to valence electrons and then the free electron takes the place of the valence electron within its atom as a result. This happens thousands to trillions of times a second as small amounts of energy are transferred between large amounts of these quantum particles. Together, their movement cumulatively make up what are measurable as amps.

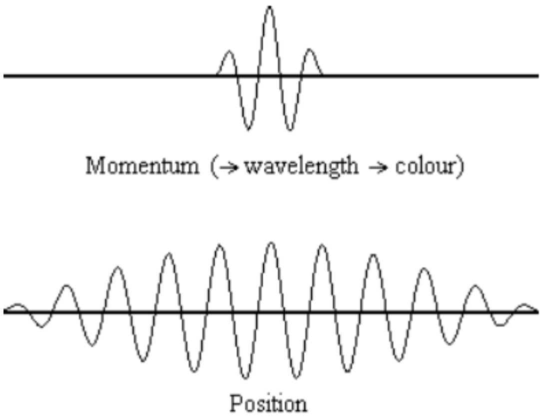

Figure 4. The inverse relationship of predicting momentum and position of electrons, and the wave like probability of determining momentum and position [1]

In order for electrons to move, there must first be a voltage present on the conductor, and as soon as the electrons have a place to move to deliver their energy, the voltage acts as pressure to push the electrons in the direction of where their energy is to be delivered. As the electrons move, they generate a current in the wire since as the carriers they are transferring energy from one position to another. It is this principle that electrons pass energy to one another creating a cycle of free electrons and valence electrons, that can be described as the traditional desk toy of Newton's Cradle. It is made up of the linear suspension of metal balls that hit one another and transfer energy through one another. This is exactly what behavior is going on amongst groups of electrons tightly packed in a conductor and transferring electrical energy from one electron to another. Electrons aren't actually traveling from a large power plant to a television at a home almost instantaneously, which is why scientists describe electrons as charge carriers.

3. Electrical Background

Alternating current and direct current are the two most commons forms of electricity utilized in the modern electric grid, which have both been heavily researched since the 1800's. The two primary common variables between alternating current and direct current are voltage and current. Voltage acts similarly to pressure in a closed system and is the potential difference within a conductor or conductors. Current is the movement of charge through a portion of an electrical conductor. Where alternating current and direct current differ is regarding their frequency measured in Hertz, which is also known as cycles. For direct current, when there is a voltage on a conductor the frequency is recognized as a positive consistent value. This can be seen in Figure 5. In alternating current in the United States, the frequency is changed 60 times a second. [7] This means that voltage and current change directions 120 times a second, which is shown in Figure 6. During each cycle, the sine wave representing voltage and current changes from positive to negative or negative to positive two times for every cycle, which is how the direction of voltage and current changes 120 times a second.

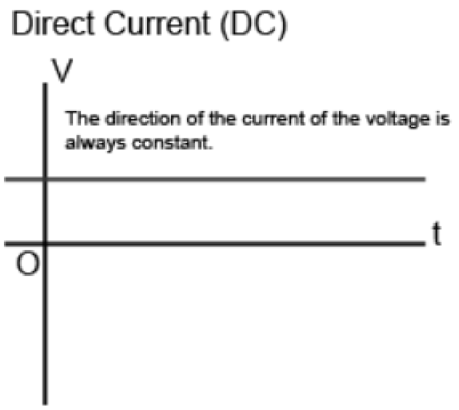

Figure 5. Frequency of voltage with respect to time in a direct current system [5]

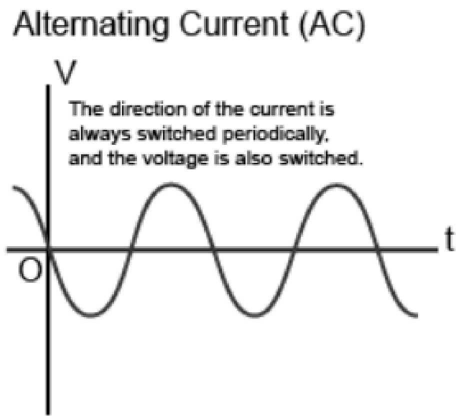

Figure 6. Frequency of voltage with respect to time in an alternating current system [5]

With the primary difference between alternating current and direct current being the frequency, it is possible to modify and develop equations that describe the movement of electrons in alternating current. The research that Michael Faraday performed in the 19th Century using an electron gun and cathode ray tube to measure the number of electrons moving through a vacuum will directly apply to this application. He performed these experiments to determine the amount of energy needed to move a specific number of electrons. His findings related to electrons directly impacted the development of computer monitors, classic "big-box" television sets, and electroplating not to mention modern transformers and generators. [5] Through the cathode ray tube experiment, he developed an equation in 1832 which related the properties of electrical and chemical change. [4] This equation will serve as the basis for development and the application in alternating current, whereas its original application was for direct current.

4. Concept

Michael Faraday discovered that electrons flowed and were measured flowing through the cathode tube ray experiment, however this cannot be done in an alternating current environment. [10] This application of an alternating current electron gun is not currently possible whereas to shoot electrons out and pull them back in. However, we can apply his measured and tested values, and the equation he developed to alternating current. The primary modification is to his concept is to apply a changing frequency. Since frequency is consistently cycling in alternating current, the electrons will not move in one direction as seen in direct current, but they will oscillate. This oscillation is represented as the values for voltage and current change from positive to negative or negative to positive values. This oscillation of electrons, represented as frequency, will be shown in Section 7.1 to calculate electron movement, and expanded in Section 7.2 to calculate the distance traveled by electrons.

5. Electron Current Equation

The equation that Michael Faraday developed can be modified and used for its application in alternating current systems to be able to determine the electron movement given a measured current in Amps. This equation is shown below as (1). [9]

$$I = q / t \tag{1}$$

When solving for coulombs the equation can be seen as:

$$q = It \tag{2}$$

This equation can be stated as coulombs (***q***) equals current (***I***) multiplied by time (***t***).

For the purposes of this research, the goal is to be able to equate a measured current to the number of electrons moving across the cross-sectional area of a conductor that created the detected current (amperage). Based upon (1), it is known how many electrons per second are moving in a cross-sectional area of a conductor to create one amp of current. Therefore, there stands a multiplicative relationship between current and coulombs or otherwise stated amperage and electrons moving per second. The equation that can be used to calculate total electron movement in the cross-sectional area of a wire per unit time is the following:

$$e_n = \frac{Iq}{t}, \tag{3}$$

Using (3), total electrons oscillating in a cross-sectional area of wire, represented as e_n, can be calculated by multiplying the current measured (***I***) and coulombs (***q***) and then divide by time (***t***). From Faraday's research, it is known that one coulomb of charge requires the movement of $6.241509x10^{18}$ electrons, which is recognized by the National Institute of Standards and Technology. [3] One coulomb is equal to one Amp and can therefore be considered a constant within this application carrying a value of 1. Within Faraday's original equation to calculate electron movement in direct current, time was equal to 1 second. For applying electron movement in an alternating current scenario, we'll adjust time in seconds to be double the frequency. Electrical frequency, measured in Hertz, is the cycles per second, where a complete cycle is the movement of current in one direction, then changing direction in an equal and opposite way. Rather than counting the movement of electrons for a full second, we're only going to count the movement of electrons in one direction for one cycle. In the United States, alternating current has a frequency of 60 Hertz, which means that the direction of current in a conductor changes 120 times a second, or two times for every cycle. [12] So rather than dividing by one second as in direct current, we're going to divide by 120 (or multiply by 1/120th of a second), otherwise noted in the equation as ***2f***. This will allow the equation to be adaptation to different electric grid operating frequencies around the world. The final electron movement calculation based on current can be noted as:

$$e_n = \frac{I\,q}{2\,f} \tag{4}$$

Using (4), we can now calculate the number of *Electrons Moved* (e_n) based upon a measured or provided current in units of Amps.

6. Electron Distance Equation

The previous section allows us to effectively calculate the number of electrons (or magnitude of the movement) oscillating in a cross-sectional area of wire, but in this section, we'll determine the distance/position of the electrons moving through the conductor. Building upon the relationship established between current and electron movement that is based upon Faraday's research, an equation can be developed to determine the distance traveled by the electrons due to a specific current. The goal is to be able to calculate the impact of electron movement within a conductor, which stated simply is the real maximum distance traveled by an electron.

In order to develop this, the following steps will take place:

1) Initialize conductor variables and values
2) Perform algebraic calculations on conductor information
3) Initialize physics and electrical variables and values
4) Perform algebraic calculations for electron movement

6.1. Step 1

To begin step 1, the conductor variables are listed below that are needed to serve as the basis for the following calculations.

Conductor Information:

Material: Element on the periodic table

Material Density: d_m : Weight per cm^3 (g/cm^3)

Free Electrons: e_a: Free electrons available per atom of material type (e/a)
Atomic Weight: w: Weight per atom (g/a)
Surface Area: A: Conductor cross-sectional area (cm^2)
Calculated Variables:
Free Electron Density: d_e: Number of free electrons / cm^3 (e/cm^3)
Free Electrons per Length of Conductor: e_l: Free electrons/cm (e/cm)

6.2. Step 2

To proceed with step 2, the values of Free Electron Density (d_e) and Free Electrons per Length of Conductor (e_l) will be shown.

To calculate Free Electron Density (d_e) with units of electrons per cubic centimeter (**e/cm³**) we will begin with the density of the material. The first step in order to solve for Free Electron Density (d_e) is to determine the number of atoms per cubic centimeter of the conductor material. The Material Density (d_m) gives the weight of the conductor material per cubic centimeter where this can be divided by the Atomic Weight (**w**) of the conductor material to determine the number of atoms per cubic centimeter as shown below:

$$\left(Atoms / cm^3\right) = \frac{d_m}{w} \tag{5}$$

To calculate the resulting *Free Electron Density* (d_e) of a conductor material, we multiply the *Free Electrons* (e_a) with the result from (5). The units will be in electrons per cubic centimeter to from (6).
Free Electron Density:

$$d_e = \left(Atoms / cm^3\right) \times e_a \tag{6}$$

To calculate *Free Electrons per Length of Conductor* (e_l) in units of electrons per centimeter, we will take the *Free Electron Density* (d_e) solved for in (6) in units of, electrons per cubic centimeter, and divide by the cross-sectional area of the conductor.
Free Electrons per Length of Conductor:

$$e_l = \frac{d_e}{A} \tag{7}$$

6.3. Step 3

To proceed with Step 3, we'll initialize the variables and their values for the electrical and physics application:
Electrical Information:
Current: f: Amperage (A)
Electron Charge: e: Constant = $\mathbf{1.6\times10^{-19}}$C
Calculated Variables:
Distance: d: Distance moved in one direction (cm)

6.4. Step 4

The final step is to calculate the distance traveled by the electrons in one direction.

To calculate the *Distance* (d) that the electrons moved we'll used the resulting values from (4) and (7). The result from (16), *Electrons Moved* (e_n), will be divided by the results from (7), *Free Electrons per Length of Conductor* (e_l), to get the *Distance* (d) in centimeters that the electrons traveled in one direction. The equation can be represented as:
Distance:

$$d = \frac{e_n}{e_l} \tag{8}$$

To combine all previous equations into one single equation for calculating electron distance we'll insert the equation for e_n (4) & e_l (7) into (8).
Distance:

$$d = \frac{e_n}{e_l} = \frac{(I\ q)/(2f)}{d_e / A} = \frac{I\ q\ A}{2f\ d_e} \tag{9}$$

Inserting (5) into (6) in for *Free Electron Density* (d_e) results in:

$$d_e = \frac{d_m e_a}{w} \tag{10}$$

Now, inserting the reorganized equation for *Free Electron Density* (d_e) as (10) to form the more detailed version in (11), which is equal to the simplified version identified as (8):
Distance:

$$d = \frac{e_n}{e_l} = \frac{I\ q\ A}{2f\ d_e} = \frac{I\ q\ A\ w}{2f\ d_m e_a} \tag{11}$$

Equations (8) & (11) will both result in the same value for *Distance* (d) for distance traveled by an electron in one-half cycle given a specific amount of *Current* (I) in a conductor measured in centimeters. This calculation does not consider the amount of resistance within a conductor and assumes it to be zero. In this case, the result to the distance traveled by an electron is the maximum distance traveled by an electron, since no conductor possesses a resistance value of zero. It is important to bear in mind that this distance calculation is for one half-cycle, and therefore to complete the other half-cycle the electron changes direction and has the potential to travel the same maximum distance in the direction it came from. Taking resistance out of the equation, since it is presumed to be equal in both directions at this microscopic scale, the electron theoretically returns to its approximate starting location relative to the macroscopic scale. The application of this equation takes it an additional step further and will put in perspective the portion of a conductor that is impacted by electron movement.

7. Application

This section discusses the application and example calculations for the equations formulated in Section 6.2 and Section 6.4. Equation (4) from Section 6.2 and (11) from Section 6.4 will be applied as an example in the following subsections.

7.1. Electron Current Example

In this example, we will calculate the number of electrons moved given a specified current and frequency in a conductor. Equation (4) below, will be used to calculate the number of electrons oscillating due to a specific current.

$$e_n = \frac{I\,q}{2\,f} \tag{4}$$

The variables and their associated values used in (4) are listed in Table 1.

Table 1. Example 1 – Variables and Values

Symbol	Variable	Value
I	*Current*	20 Amps
$\boldsymbol{q}$	*Coulombs*	$1C = 6.241509\ x\ 10^{18}$ electrons
$\boldsymbol{f}$	*Frequency*	60 Hertz
$\boldsymbol{e_n}$	*Number of Electrons*	To Be Calculated

The current used in this example is 20 Amps, which is common in many homes and businesses. The frequency used is 60 Hertz, which is used in the United States electric grid. [12] The value for Coulombs is 1, which is equal to $6.241509\ x\ 10^{18}$ electrons. [11] Placing the values of each variable in (4) is seen in (12) below:

$$e_n = \frac{I\,q}{2\,f} = \frac{(20)\left(6.241509x10^{18}\right)}{2(60)} \tag{12}$$

Solving for the *Number of Electrons* ($\boldsymbol{e_n}$) in (12) results in $1.0402515\ x\ 10^{18}$ electrons oscillating through a cross-sectional area of a wire to measure 20 Amps of current.

7.2. Electron Distance Example

In this example, we will calculate the number of electrons moved given a specified current and frequency in a conductor. Equation (4) below, will be used to calculate the number of electrons oscillating due to a specific current.

$$d = \frac{I\,q\,A\,w}{2\,f\ d_m e_a} \tag{11}$$

The variables and their associated values used in (11) are listed in Table 2.

Table 2. Example 2 – Variables and Values

Symbol	Variable	Value
$\boldsymbol{I}$	*Current*	20 Amps
$\boldsymbol{q}$	*Coulombs*	$1C = 6.241509\ x\ 10^{18}$ Electrons
$\boldsymbol{A}$	*Surface Area of Conductor*	0.331 cm^2
$\boldsymbol{w}$	*Atomic Weight*	$1.055\ x\ 10^{-22}$ grams
$\boldsymbol{f}$	*Frequency*	60 Hertz
$\boldsymbol{d_m}$	*Material Density*	8.94 (g/cm^3)
$\boldsymbol{e_a}$	*Free Electrons*	1 Electron/Atom (e/a)
$\boldsymbol{d}$	*Distance*	To Be Calculated (cm)

The values for *Current* ($\boldsymbol{I}$), *Frequency* ($\boldsymbol{f}$), and *Coulombs* ($\boldsymbol{q}$) are the same as in the previous example. Copper is the most common conductor material used in homes and businesses and has one *Free Electron* ($\boldsymbol{e_a}$) available per atom. Copper also has an *Atomic Weight* ($\boldsymbol{w}$) of $1.055\ x\ 10^{-22}$ grams, and a cubic centimeter of copper weighs 8.94 g/cm^3. [14,15] A common wire size for circuits in homes and buildings is utilizing 12-gauge wire, which has a cross-sectional area of copper that is 0.331 cm^2. [4,13] Placing the values of each variable in (11) is seen in (13) below:

$$d = \frac{(20)\left(6.241509x10^{18}\right)(0.331)\left(1.055x10^{-22}\right)}{2(60)(8.94)(1)} \tag{13}$$

Solving for the *Distance* ($\boldsymbol{d}$) in (13) results in $4.063322\ x\ 10^{-6}$ cm that the oscillating electrons travel in either direction inside of a 12-gauge copper conductor given a current of 20 Amps.

8. Conclusion

The *Quantum Movement Theory* through the application of Equations 4 & 11 provides a quantifiable method to determine electron movement in a conductor. This theory and mathematical representation provides clarity and understanding for what is occurring inside of an electrified conductor. This article and method provided can be used in both particle physics and electricity. As demonstrated empirically, electrons deliver and transfer energy via oscillations and now we have two equations that we can use to describe these quantum interactions that impact our macroscopic world.

The application of this concept refutes these claims, by showing that the electron flow doesn't exist in an alternating current environment and therefore FERC shouldn't have direct regulatory authority over distributed generation assets.

This research stands to contribute to future developments of electrical designs and experimentation. From a research aspect, this theoretical concept could serve in 1) future development of low resistance conductors, 2) materials science in developing super conductors used with alternating current, 3) the development of devices with controlled electron movement including experiments similar to cathode tube rays combined with alternating current.

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