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P6_6 The Power of the Forks: Harnessing Lightning Power

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Abstract
The power of lightning and the fraction of that which is available to us is explored in this paper. We find that exploiting Joule heating we can harness $7.5 \times 10^4 J$ of energy per lightning strike, and by using a bank of capacitors we can harness up to $2.5 \times 10^5 J$. The total power available by these methods in every strike that occurs on Earth is $11.25MW$, six orders of magnitude less than the Earth's power consumption.

Introduction

Following a paper by Szczykulska et al. (2013) [1] in which the vast power of lightning was quantified, we shall consider possible methods for harnessing some of the power released by lightning strikes. It was shown that a single bolt of lightning liberates $7.5 \times 10^7 J$ [1]. Although this figure obviously has large inherent errors due to the random nature of lightning, we shall henceforth consider an average bolt which yields exactly this amount of energy. We shall examine the heating effect of lightning strikes on conducting ground rods, and also the possibility of using capacitors to store some of the energy.

Heating Effect

It is well known that Joule heating occurs within any non-superconducting conductor with a power

$$P_J = \frac{V^2}{R} = I^2 R \tag{1}$$

where V, I, and R are the voltage across, the current flowing through, and the resistance of the conductor respectively [2]. Szczykulska et al. show that despite current not being constant throughout the strike, an average current of $10kA$ is an appropriate approximation. Kirchoff's Laws [3] state that this current must be equal in the ionized air column and in the grounding rod, if present, assuming each stroke is grounded in one location only. We shall consider now a grounding rod designed to channel the current from the lightning and convert some energy into heat. Lightning protection rods for buildings should have resistances of not more than 10Ω [4] and as such we shall use this figure for our theoretical rod. We then use Eq. 1 to give $P_J = 10^9 W$ as the electrical power converted to heat by the rod.

It is worth noting that this assumes the resistance is constant despite this heating effect. Although for most materials this is not true, for some designer materials such as Manganin® the electrical resistivity changes by less than 1% for temperature changes of several thousand Kelvin [5]. As such we shall neglect the change in resistivity this heating causes. Multiplying this power by the duration of a strike ($100\mu s$) [1] we obtain a total energy converted into heat of $10^5 J$. To justify our assumption that the resistivity is almost constant we can show that the temperature change in a $10kg$ rod of Manganin® is only $24K$ [6], giving a change in resistivity of 1 part in 21,000 [5].

Suppose now that the rod we considered is made hollow and has a flow of water through the centre. This heat energy will be transferred into the water (assuming effective thermal insulation on the outside of the pipe) converting it into steam. As this will be a sudden process and not constant, regular steam turbines will be ill-suited to harnessing this energy. Impulse turbines however are becoming more widespread and are designed to accommodate sudden spikes in energy input. The efficiency of modern impulse turbines can be as great at 75% [7]. We can then conclude that for any single bolt of lightning as much as $7.5 \times 10^4 J$ can be successfully converted into useful energy. This may seem like a very large number, however it is less than 0.5% of the power harnessed from combustion of $1kg$ of coal [8].

Using Capacitors

Lightning generates incredibly large voltages and current flows, some of which may be used to charge a capacitor. Szczykulska et al. explain that the dominant current in a strike usually flows from the ground to the cloud [1] and as such the electrons must flow from the cloud to the ground. We assume here the electrons are the mobile charge carriers as their mass is very small compared to that of any of the positive particles present. We propose a capacitor connected to a lightning rod as shown in Figure 1.

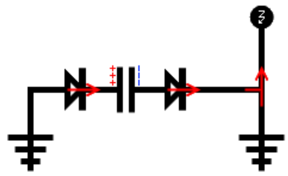

Fig. 1: Schematic diagram of a proposed circuit to harness the power in a lightning strike by means of a grounded capacitor. The red arrows depict the flow of current (electrons will flow anti-parallel to this). The coloured icons beside the capacitor show the build-up of charge that develops on the capacitor plates. The circular icon at the top of the picture denotes the top of the lightning rod.

The majority of the current will obviously flow through the grounding rod and directly into the ground, but a large electric field will be generated across the capacitor plates. The voltage generated can be found from Eq. 1, knowing the power in the stroke and the resistance of the rod. This voltage is $V = 10^5 V$. The diodes in Figure 1 are in place to prevent immediate discharge of the capacitor. Since common capacitors cannot withstand voltages of more than a few hundred Volts [9], upwards of 100 individual capacitors must be used in series configuration. The energy U that can be stored in a capacitor is given by

$$U = \frac{1}{2}CV^2 \tag{2}$$

where C is the capacitance of the capacitor and V is the voltage across it [10]. For high end capacitors with $C = 10mF$ [9], and assuming 200 capacitors each with $500V$ across them, this gives a value for the total energy stored as $U = 2.5 \times 10^5 J$. This is more than three times the energy yield from Joule heating of the rod, although is still less than 2% of the energy yielded from combustion of $1kg$ of coal [8]. Using this method to harness the energy from every single bolt of lightning that hits the Earth [1], we can only expect an average power output of $11.25MW$, less than one millionth of the total power consumption of the planet [11].

Conclusion

It appears that the energy generated from lightning is too little to be of any real use. Even if we can use the capacitor method described above to harness the energy from every single bolt of lightning that hits the Earth we can only expect an average power output that is less than one millionth of the total power consumption of the planet [11]. For this reason we conclude that lightning power is not a suitable source of energy for the world. We have also not considered the difficulties in constructing the structures required for these methods, which would most likely be very complex.

References

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