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# P4_2 Using the Forks: The Energy Yield of a Lightning Bolt

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**Abstract**

Lightning may be considered as a potential energy source if the yield is comparable to other renewable energy sources. The energy yield of one strike was evaluated to be 7.5×$10^7$ J, where approximately 50 strikes produce a yield equivalent to that of an average wind turbine in a year. This indicates that lightning may be a viable energy source of the future.

## Introduction

Natural lightning produces very high quantities of power through electrical discharges. However, a lightning bolt has a very short lifetime, thus the total energy produced by a single event may not be as great as would be expected. For lightning to be considered as a viable energy source, the potential energy yield of a single bolt must be calculated.

## A Lightning Bolt's Life

Each lightning strike consists of an initial 'leader' stroke, where a path of current flow is established between the cloud and the ground through 'steps'. The path is an ionised channel of air, thus very conductive. A current is allowed to flow between the cloud and the ground once the path reaches a point on Earth [1].

The greatest current in a lightning strike flows upward towards the cloud. This is due to the fact that the charge held in a thunder cloud attracts particles of the opposite charge in the earth (the cloud usually holds the negatively charged particles), thus once a path is established these particles surge towards the cloud, forming a very large current [1]. A surge like this occurs three or four times in a single strike on average, interspaced between downward current flows [1]. However, a system which can capture the upward current would be more complex than a system which only captures the current from the charge-carrying cloud. This is due to the upward current being dependent on the ionised path reaching the ground, thus any system designed to capture the current must counter the effects of grounding in a circuit.

## Lightning Voltage

Calculating the yield of a lightning strike which never reaches the ground may be useful in determining whether the potential yield in upward strokes is worth the extra expense in more complex systems. In fundamental terms, Ohm's law can be expressed as follows:

$$P = IV, \tag{1}$$

where $P$ is electrical power, $I$ is current and $V$ is voltage. This relation can be used to determine the power output of a lightning bolt with a known current and voltage.

A minimum voltage for the lightning bolt can be assumed by taking the breakdown voltage of air in storm conditions. This is the minimum voltage required for an arc (i.e. a strike) to occur over a given distance. If the storm clouds are assumed to be plane parallel with the ground, Paschen's law can be used to calculate the breakdown voltage [2]. Equation 2 gives Paschen's law below.

$$V_{break} = \frac{apd}{\ln(pd)+b} \ , \tag{2}$$

where $V_{break}$ is the breakdown voltage, $p$ is the atmospheric pressure, $a$ and $b$ are parameters dependent upon the composition of the gas to be traversed and $d$ is the distance the arc must travel. This formula gives the breakdown voltage for a 1 metre arc in standard conditions for temperature and pressure (STP) to be 3.4 MV [2], where $a$ = 4.36×$10^7$ V·atm$^{-1}$·m$^{-1}$ and $b$ = 12.8.

However, storm conditions will differ from STP; humidity will be greater and atmospheric pressure will have dropped. Thus, the breakdown voltage per unit length is approximated to 3 $MVm^{-1}$. Since the leader stroke is a series of steps which can be considered as separate arcs, the minimum voltage for lightning can be calculated taking *d* as the average length of one step. This length has been estimated to be approximately 50 metres [3], thus the minimum voltage in a bolt of lightning is 150 MV.

## Lightning Current

If the magnetic field can be accurately measured around the path of the bolt, Ampère's law (equation 3) can be used to find the current in a lightning bolt, treating it as a wire.

$$B = \frac{\mu_0 I}{2\pi r}, \quad (3)$$

where $\mu_0$ is the permeability of free space and $r$ is the distance from the current where the magnetic field strength $B$ was measured. Generally, a peak current between 5 and 20 kA is measured [3].

## Energy Yield

These values for current and voltage give a peak power output of $1.5\times10^{12}$ W if 10 kA is used as a typical value for peak current. Furthermore, to calculate the energy yield the time duration of the strike is required, as well as time-dependences of voltage and current. Voltage can be considered constant, since no variable in Paschen's law changes in the lifetime of a lightning bolt. This leaves only the time-dependence of the current to be evaluated. A strike's current increases rapidly to its peak within 1-10 microseconds (μs), followed by a much slower exponential decay which lasts hundreds of microseconds before the path breaks up [2]. For a general case, approximating the current to a constant flow at half the true peak for the entire strike duration serves as an appropriate model (see figure 1).

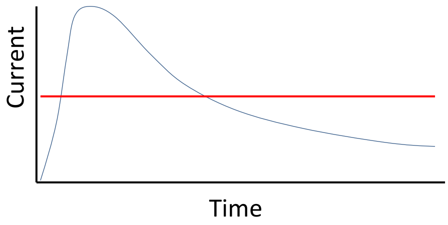

Figure 1: The blue line demonstrates the current in a typical strike [2], the red line shows the constant-current approximation used. The area beneath each graph (proportional to energy yield) is approximately equal. (Original source)

Using 10 kA [3] and 100 μs [2] as typical values for the current's peak voltage and the strike duration respectively, equation 4 can now be used to determine the yield of a typical lightning strike.

$$E = Pt = IVt, \quad (4)$$

where $E$ is the energy yield and $t$ is the time duration of the strike. This gives a result of $E$ = $7.5\times10^{7}$ J. Annually, an average wind turbine produces $4\times10^{9}$ J (this was calculated via taking data of the total energy generated by turbines and dividing it by the total number of turbines in operation worldwide) [4]. Assuming the total energy can be stored or immediately used, a lightning receptacle would have to receive over 50 lightning strikes a year to produce the same yield. With further research into the frequency of thunderstorms per unit area worldwide, an estimate for the area of land where lightning receptacle could generate comparable energy yields can be calculated. Additional research can also be made into the costs of building lightning receptacles, thus making possible an evaluation of the financial viability of such systems.

## Conclusion

The results in this report show the energy yield from a lightning strike directly from a thundercloud may be high enough for lightning to be a viable energy source. Further research into both capturing upward currents in cloud-to-ground strikes and geographical frequency of thunderstorms is required to determine whether lightning produces cost-effective energy yields.

## References

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[3] –Ahrens, C.D. (2008), "*Meteorology Today*" 9th edition, Thomson Brooks/Cole.

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