Laser-induced lightning for electric energy generation

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Introduction

Laser triggered lightning is an extensively researched area that is currently being pursued in many international institutions. Different institutions ponder on different prospects of laser induced lightning. Some groups are interested in spectral studies regarding aerospace and environmental concerns but others investigate for protection of key installations such as research centers, substations, power houses and military depots. Our objective in this research is to use the art of laser induced lightning for electricity generation applications. Advances in ultrafast optics in recent years have revived a keen interest in laser-induced dielectric breakdown study. While it is widely accepted that femtosecond laser pulses with peak powers reaching gigawatts can propagate over tens of meters under laboratory conditions, the dynamics underlying this highly nonlinear phenomenon is yet not fully understood. Although initial research on laser-triggered lightning was started with infrared lasers, it was found that they are not suitable to initiate lightning. Recent published literature and experimental work favor the use of ultraviolet laser pulses as the appropriate means for laser-induced lightning discharge. An analytical solution based on Maxwell's equations has been developed for ultraviolet filamentation in air, arising from a dynamic oscillating balance between self-focusing, diffraction and plasma defocusing. This model suggests that ultraviolet (220 – 420 nm) 200 picosecond laser pulses with a peak power of around 50 MW (or 12.5 mJ input energy) and a beam size of 100 μm as the optimal tool to trigger outdoor lightning. The laser beam size remains relatively small (less than 0.3 mm) after a propagation distance of 200 m up into the normally cloudy atmospheric conditions. Rocket-triggered lightning experiments, which can be seen as a modern day version of Benjamin Franklin's kite experiments, have been reported to successfully discharge electrified clouds in skies up to a success rate of 60 % in New Mexico. Using this technique, a rocket, tied to a large spool of wire connected to earth, was launched into the thunderclouds above. The time of launching of the rocket was determined by monitoring the electric fields underneath the thunderclouds. Although this technique may appear feasible, it has a few setbacks. Firstly, the launching of numerous projectiles into the sky followed by their potentially dangerous downfall makes it less attractive to divert lightning from sensitive places like substations and power grids. Secondly, the rocket should be fired at very great speeds into the sky to prevent an accumulation of space charges that can effectively shield it. Thus, the rocket speed should be greater than 2×10^5 m/s, the downward speed of a stepped leader in a lightning process. These shortcomings could be easily overcome with a laser-induced lightning discharge. This study can be implemented in several steps such simulation of beam propagation, air ionization characteristics, laser design of suitable power, filamentation studies and investigation of appropriate wavelength, energy and pulse durations for successful triggering of air under clouds to cause soft plasma channel to download charges.

Materials and Methods

In this technique, a collimated laser beam is used to ionize the air, thus creating a preferential conducting path for free charges in the sky to flow down to earth on a faster and more reliable basis. This follows from the above argument that if lightning can be diverted, it may also then be probable to store these atmospheric electrical charges through the use of conducting electrodes and capacitor banks. Once the plasma filament is created through laser ionization, stray charges are collected from electrified clouds during thunderstorms or from the ionosphere in clear sky weather. These charges will flow through a conductive electrode as they reach closer to ground to avoid the possibility of artificially triggering a lightning discharge that may destroy the laser system. This electrode will then pass these charges onto a capacitor bank to store these charges. Utilizing this form of atmospheric electricity may provide a new alternative source of energy in the future, while discharging a thundercloud and thus reducing potential lightning strikes at sensitive airborne operation and ground installations. The project was carried out by simulation studies of beam propagation in air and design of CO2 laser to experiment the charge collection. Both works were carried out to maximum depth using a self-written simulation program using Fortran 77 and fabrication of CO2 laser in power engineering lab.

Results and Discussion

In deciding the best-suited parameters for long distance propagation of UV laser pulses in air, theoretical investigations have been conducted for the following conditions: 1- Different beam sizes with the same input power and 2- Different input powers of the same initial beam size. Setting the input power P to be constant at 50 MW for various beam sizes w of 80 μm, 100 μm, 200 μm, 400 μm, the following graphs were obtained. Based on results, w_0 = 100 μm appears to be the best choice for an initial beam size parameter. For this value, the beam size remains the smallest (and thus higher laser intensity trapped in the filament) after a propagation distance of 200 m. Results further consolidates this choice. Although the power attenuation factor is largest when w_0 = 100 μm, the laser intensity in the beam is the highest (roughly 4.8×10^{14} W/m^2) compared to w_0 = 1000 μm (lowest power attenuation factor) with an intensity of 8 x 10^{14} W/m^2. It is important to remember that laser intensity (rather than the input power) plays a very important role in the multiphoton ionization process, generating free electrons that will facilitate the initiation of a lightning discharge, as supported by Equation (2). The laser intensities associated with the remaining beam sizes 80 μm, 200 μm and 500 μm are roughly 2.69 x 10^{14} W/m^2, 9.2 x 10^{12} W/m^2 and 1.3 x 10^{12} W/m^2 respectively. However, when the input power was set at a constant 100 MW, 80 μm appears to be the best initial beam size with an intensity of about 2.7 x 10^{14}W/m^2. This intensity is still lower than that achieved with a laser beam size of 100 μm and input power of 50 MW although the energy requirement on the laser has now been doubled. Thus, a 50 MW UV laser pulse with a beam size of 100 μm is still the preferred choice. Different input powers (50 MW, 100 MW and 200 MW) with a (constant) initial beam size w_0 = 100 μm were used to test the validity of using a 100 μm beam size. It displays a minimal beam size variation when P = 50 MW was used. After a propagation distance of 200 m, the beam size remains smaller than 0.3 mm in radius. One may also expect a large beam size modulational instability for input powers greater than 200 MW. The 50 MW input power filament also shows the least power attenuation factor while maintaining the largest beam intensity after propagating more than 200 m in air.

Conclusions

Through the simulation work and within the limits of the model presented, it is concluded that ultraviolet (with a central wavelength of 248nm) laser pulses with pulsewidth of 200ps, peak power 50MW and a beam size of 100 μm are seen as the optimal tool to initiate outdoor lightning. One may increase the peak power of a laser pulse by decreasing the pulse duration (or the pulsewidth) while maintaining the same input energy. For this reason, the input energy of a laser beam is vital only for determining the peak power of a laser pulse. As long as the laser peak power remains larger than the critical power, P_{cr} self-filamentation of UV pulses takes place. It is also evident from the simulation that the laser beam size remains small (less than 0.3mm in radius) even after propagating a distance of 200m in air. These optimized laser beam parameters produce the least power attenuation of the beam and also the least variation on the overall beam size (as compared with those associated with higher initial peak powers and bigger initial beam radii). With high peak powers (larger than 100MW), the power trapped in the UV filaments undergoes a drastic decay for the first 30m before finally reaching a lower power threshold of 50–60MW. The overall filament size, at first, decreases to a minimum at a distance of 20–30m. Beyond this point, the beam size increases almost exponentially (for the higher peak powers).

Benefits from the study

The benefits of this study include but not limited to recognition of UPM internationally as a research university. In addition, three to four students got MSC degrees out of this funding from this project. A few Malaysian youngsters got research experience as RA reducing employment burden on the government. The University has got more equipment and improved on its research facilities to attract foreign students.

Several International research groups invited UPM to join international research ventures. UPM got 15 Watt laser facility that was designed at the university using raw materials, and developed laser design expertise accepted internationally through papers, which will help other researchers.

Patent(s), if applicable:

The research conducted also created possibility for us to register two patents.

Stage of Commercialization, if applicable

Two patents are pending registration, we need more money to register it with SIRIM. CO2 laser is under consideration for marketing in near future. Still more work needed to configure it to market requirements.

Project Publications in Refereed Journals

1. N. Khan, N. Mariun, I. Aris and J. Yeak. Laser triggered lightning discharge, *New Journal of Physics, IOP, UK*, Vol.4, 6.1-61.20, August 14, 2002.

2. N Khan, N Mariun, I Aris, M Zaki, and L. Dinish. Transient analysis of pulsed charging of supercapacitors, *SIRIM Journal of Industrial Technology*, Vol. 10, No.1, November 2001. pp141-154

Project Publications in Conference Proceedings

1. S. Sidu, N. Khan, N. Mariun, S.J. Ikbal. Cost Effective Design of Sealed CO_2 Laser, *Proc of World Engineering Congress 2002*, 22-24 July 2002, Kuching Sarawak, Malaysia.

2. Nasrullah Khan, Norman Mariun, Jeremy Yeak. Transient Analysis of Pulsed Charging in Supercapicitors, *IEEE, TENCON 2000*, Renaissance New World Hotel, Kuala Lumpur, 25-27 September 2000.

3. Norman Mariun, Nasrullah Khan, Hartono Zainal, Zen Kawasaki. Prospects of atmospheric electricity in Malaysia, Annual Conference of Society of Atmospheric Society, Akita, Japan, 13-14 July 2000.

4. Nasrullah K, N. Mariun and J. Yeak. Atmospheric Electricity- The new alternative source of energy, Energex 2000, July 15, 2000, Las Vegas, USA.

Graduate Research

	Name of Graduate	Research Topic	Field of Expertise	Degree Awarded *(e.g. M.SC/Ph.D.)*	Graduation Year *(or expected)*
24.	Shahid Iqbal	CO2 laser design	Electrical Engineering	MSC	2002
25.	Jeremy Yeak	Simulation of beam propagation in air	Electrical Engineering	Thesis submitted for MSc	2003

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