26PA12 Thunderstorm locating and laser triggered lightning of electrical discharge

S. Uchida, Y. Shimada, H. Yasuda, C. Yamanaka
Institute for Laser Technology,
Nakoji 3-11-20, Amagasaki, Hyogo, 661 Japan
Tel 81-6-492-7613
Fax 81-6-492-5641
Y. Ishikubo, N. Shimokura
Kansai Electric Power Co,
Nakoji 3-11-20, Amagasaki, Hyogo, 661 Japan
Tel 81-6-494-9731
Fax 81-6-498-7662
K. Matsu-ura, Z-I. Kawasaki, D-H. Wang
Faculty of Engineering, Osaka University,
Yamada-oka 2-6, Suita, Osaka, 565 Japan
Tel 81-6-878-7134
Fax 81-6-878-7134
S. Nakai, T. Yamanaka, Y. Izawa, H. Fujita
Institute of Laser Engineering, Osaka University,
Yamada-oka 2-6, Suita, Osaka, 565 Japan
Tel 81-6-876-3000
Fax 81-6-877-4799

Introduction

When an intense laser light is focused in air and the intensity is beyond the threshold of the air breakdown, laser plasmas are formed. Using the conductivity of plasmas, induced electrical discharges of thunder clouds can be triggered. It was experimentally shown that a long plasma channel has a guiding effect on electrical discharges [1]. In our experiments, up to 8.5 m of guided discharges were induced at 1 MV applied voltage in laboratory. A US research group made an attempt to trigger lightning using a laser in mid 70's[2]. However, the experiment was unsuccessful due to the shortage of the laser power. Recently Japanese research groups found that the thunder storms in the Hokuriku region seem to be suitable for laser triggered lightning (LTL) experiment because the height of the clouds is relatively low which leads to the high electric fields to the ground. The high electric fields can easily initiate a leader propagation in plasma channels.

Approximately two-thirds of the power electric line accidents are caused by thunderbolts. Thus active methods to prevent the thunder faults are expected. The study of rocket triggered lightning started 10 years ago and has been successfully operated more than one hundred lightning strikes. The method utilizes a grounded wire launched into air by a small rocket and initiate electric leader propagation from the top of the wire to trigger lightning. The LTL scheme has certain advantage over the rocket method in terms of response time and residual debris such as rocket itself and grounded wire. These factors become important when the method is applied to protect live power facilities.

For successful LTL experiments, it is very important to locate the position of thunder clouds. In general, the right timing for the laser irradiation is when the electric field is strong enough for the leader propagation. The electric field of thunder can be very localized and a monitoring system might mislead the laser timing decision. Therefore, the extended diagnostics system is one of the key issues for LTL experiments.

This paper reports the present status of the field experiment for LTL. The field experiment consist of two systems, laser-plasma forming system and thunderstorm diagnosing system. The characteristics of laser propagation in atmosphere is also a important factor since it determines the amount of energies producing the plasma channel.

Laboratory experiments for laser induced long gap discharges

Figure 1 shows the 8.5 m long gap discharge induced by a 7.5 m plasma channel. The laser energy was 100 J and was focused by a multiple focusing optics called "MACH (Multi-

Active CHannel)" mirror [3]. 1-MV impulse was applied to the upper rod electrode. This result shows that approximately 13 J/m laser energy density can guide the electrical discharge.

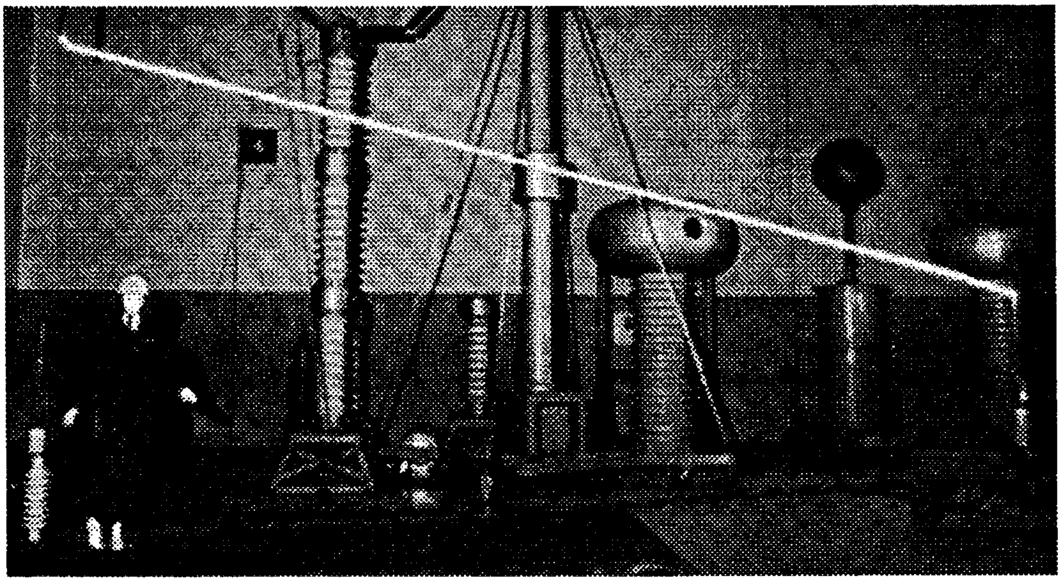

Figure 1 An 8.5-m-long gap discharge induced and guided by a laser produced plasma channel.

Plasma channel forming system

The laser-plasma forming system of the LTL experimental site is depicted in Fig. 2.

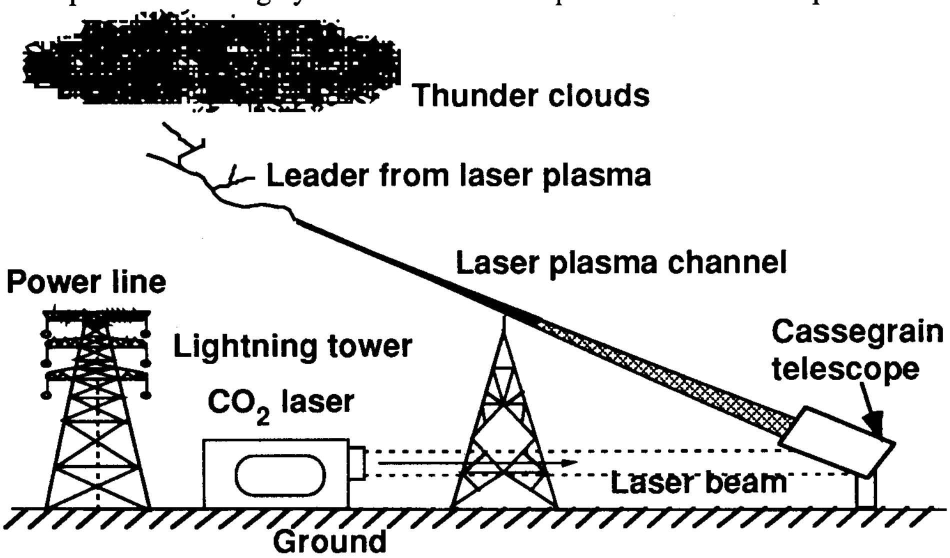

Figure 2 Schematic of the laser triggered lightning (LTL) experimental site.

The system consists of a laser system, a focusing optics, and a lightning tower. We use a high power CO_2 laser system to produce a plasma channel at the top of the lightning tower. The laser is an electron beam controlled CO_2 laser, Lekko II, and delivers approximately 1 kJ in 40 ns. The laser cavity is an unstable resonator and the beam pattern has a concentric shape (inner and outer diameters are 40 and 220 mm respectively).

The height of the tower is 50 m to enhance the ambient electric field under thunder clouds. The enhanced electric fields assist the plasma channel to initiate a leader propagation. The height of the tower is based on the results of laboratory experiments and calculations. It is important to keep high intensity and long focusing of the laser beam simultaneously to produce a long plasma channel at the focus. Laboratory experiments have been carried out successfully to determine the adequate parameters for the plasma channel formation and to induce electrical discharge using a CO_2 laser of 150 J output. A large-aperture (50 cm in diameter) Cassegrain telescope has been prepared. The MACH mirror was used for the secondary mirror to produce a multi-focused long plasma channel.

Thunderstorm locating system

As is described earlier, LTL requires a precise prediction of the right timing for laser irradiation. The prediction is possible with extended knowledge of the thunderstorm activities such as the distribution of space charge and cloud particle, and the size of cloud itself. Although, the field strength at the lightning tower is determined by a local distribution of space charge and charges in thunder clouds, the development of thunderstorm activity must be monitored with an extended time and space range to predict if the storm becomes significant at the experimental site. The thunder storm monitoring system includes SAFIR system, wide-band slow antennas, and field mills. In addition to it, radar data of the thunder storm activities are available from Kansai electric power Co. and the group of Hokkaido University.

The thunder storm monitoring with the longest range is the SAFIR. The system works as an EM wave interferometer to detect the direction of the VHF waves originating from the leader propagation of lightning and determines the location of the lightning activities. The current system consists of three antenna sites each separated by 100 km. The system detects only lightning strikes and not the development of thunder storms.

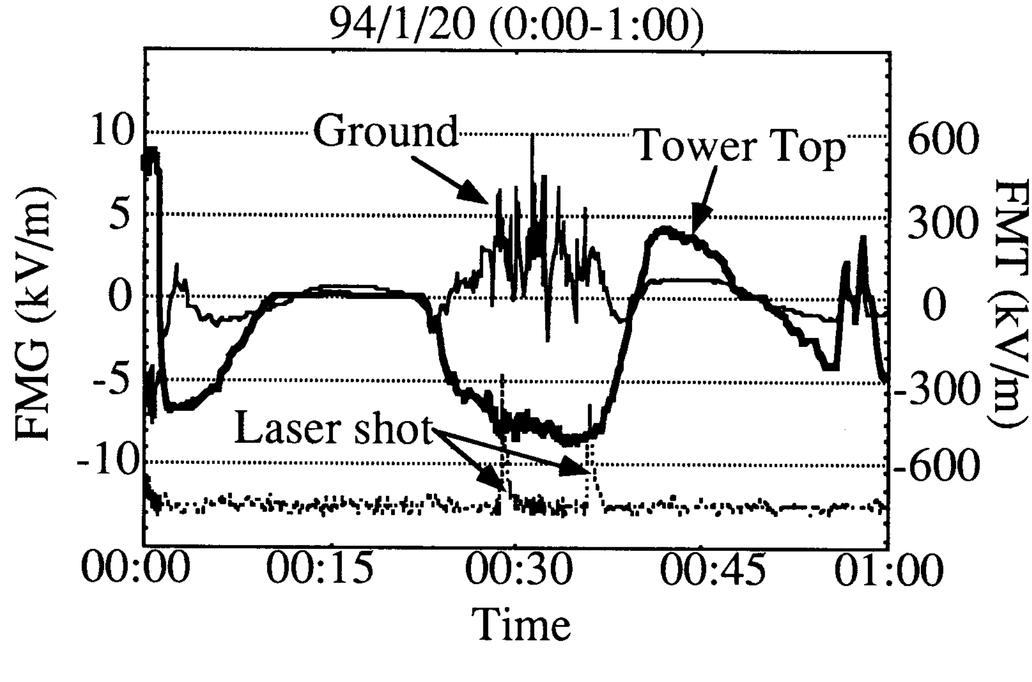

Figure 3 Time elapse of the electric fields at the top of the tower (thick line) and on the ground (thin line).

The wide-band slow antenna system covers the electric field variation due to the lightning activities within the range of 10 km. The current system consists of three antennas separated by 5 km and responds up to kHz field variation. The measurements requires 1-μs synchronization between the antennas which is provided by monitoring the GPS (Global Positioning System) signal. The system provided the lightning path with the accuracy of a few hundreds meters.

The local monitoring system is field mills. The field mill detects ambient DC-field which was considered to directly determine the laser irradiation timing. Two detectors were located at the top of the lightning tower and on the ground, 80 m away from the tower top. However, the measurements occasionally seem to be mislead by locally concentrated space charges. Figure 3 shows the time elapse of the field mill measurements .

In general, the tower-top and on-the-ground field mills indicate the similar field trends. However, in this particular measurement, polarity of the field mills reversed between the tower top and on the ground, phenomenon observed many times during the experiments. This polarity-reverse phenomenon can be due to a space charge distribution of small scale structure of the order of a few tens of meters. When such a space charge structure exists, the electric field of the thunder cloud will be shielded or even the polarity reverse takes place. In other incidence when several lightning strikes took place near the site (the closest one was 350 m away), the field mills observed the polarity reverse. In this particular case, the tower top field was over 500 kV while the on-the-ground field was near zero. These observations indicate that the determination of the laser irradiation timing cannot depend on the field mill measurement alone.

Radar data of the thunder cloud are provided by courtesy of the group from Hokkaido University (Prof. Ueda's group). Their dual-polarization Doppler radar is capable of distinguishing between rain, snow, and hail particles in clouds and measuring their velocity. This radar was located approximately 10 km away from the LTL site. In addition, data from Kusuya radar site will also be available from this winter experiment. The radar data clearly show the growth of the thunder clouds and a strong reflection of a bunch of hail over the LTL site at the time of the lightning strikes.

The right timing of the laser irradiation shall be determined both by the local field measurements, i. e. field mills, and the mid-range radar measurement. Especially the radar measurement can provide the strength and the size of the thunder storm and can be very important to determine if the laser should be irradiated. The radar data was not available on real time basis and should be monitored by the LTL site all the time.

The authors' group is preparing a radar data monitoring system which transfers radar data from Kusuya radar site (about 15 km away) to the LTL site. Using this system, the real time thunderstorm condition will be available at the site and the laser timing will be more accurate.

Laser propagation experiments

The laser propagation was characterized by measuring the transmission of laser energy through various atmospheric conditions in LTL field site. The measurements were performed under fine, rain, snow and hail conditions. The laser light propagated 50 m horizontally to an energy meter in the experiments. The experimental results show that the rain fall does not affect the transmission very much (more than 95 % at 0.7 mm/hour, typical precipitation for the site) while snow does affect the propagation as much as 50 % at 1 mm/s snow fall. Hail has similar effects as snow fall. Therefore, 1 kJ laser energy is sufficient for producing a few tens meters of plasma channel.

Summery

An LTL field experimental site has been assembled to test the laser and focusing system as well as the laser induced thunder lightning system. We have developed the Cassegrain telescope for laser plasma channel production at the top of the lightning tower and verified that the system is capable of producing a few tens meters of plasma channel with 1-kJ CO_2 laser energy. The thunder storm locating system has been provided to get the data of thunderstorms. The laboratory experiments have already performed successfully to prove that an 8 m electrical discharge can be induced by a laser plasma channel. Field experiments are now in preparation.

References

1) E. Fujiwara, Y. Izawa, Z. Kawasaki, K. Matsu-ura and C. Yamanaka, Rev. of Laser Eng. **19**, 528 (1991).
2) C. W. Schubert and J. R. Lippert, IEEE Int. Pulse Power Conf., (1979).
3) S. Uchida, *et al.*, Conference on Lasers and Electro-Optics, (1993).