Measurements of Electric and Magnetic Fields due to Lightning Strokes Based on Single-station Detection

W.I.Ibrahim
Sustainable Energy & Power Electronics Research (SuPER)
Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang
wismail@ump.edu.my

M.R.Ghazali
Control & Instrumentation (COINS)
Faculty of Electrical & Electronics Engineering
Universiti Malaysia Pahang
riduwan@ump.edu.my

Abstract— **A simple technique to determine the distance of the lightning strikes using single- station detection is described. The technique is based on ratio of the magnetics field to the electric field generated by the lightning stroke. A wire antenna was used to measure the electric field signals while magnetics loop antenna was used to measure the electromagnetics signal on the thunderstorm days. The LabVIEW software was used as a data logger to measure, analyze and calculate the lightning distance from the apparatus to the lightning stroke. The detection of the lightning activity using the developed system has been compared and validated to the Pekan Lightning Detection System (PLDS).**

Keywords-component; Electric field; electromagnetics field single- station;lightning;Pekan lightning detection system.

I. INTRODUCTION

The lightning discharges radiate electromagnetic pulses in a wide frequency range from a few Hz up to several hundreds of MHz. Based on the electromagnetic signal emitted by the lightning source, the location of lightning, its magnitude and types of discharge can be determined. The lightning location such as the information of distance and direction of lightning strike has been performed by multi-station or single-station technique.

Multi-station techniques are the most accurate to detect the location of lightning strike. The magnetic direction finder (MDF), time of arrival (TOA) and interferometry are mainly three kinds of multi-station lightning location technique used widely in the world. MDF [1] basically consists of two orthogonal magnetic loop antennae and one flat plate electrical antenna. Vertical and orthogonal magnetic field loops are used to obtain lightning direction because the ratio of the signals in the two loops is proportional to the tangent of the angle to the source.

MDF network requires at least two stations and the intersecting point of two directions from the two MDFs gives the source location. Higher accuracy could be achieved if more than two MDFs are arranged. The time of arrival (TOA) [2] technique is based on the fact that a lightning signal would arrive two different stations at a different time. The distance can be directly calculated from the time of arrival as signals travel with a known velocity [3].

TOA data from two base stations will narrow a position to a circle; data from third base station is required to resolve the precise position to a single point [4]. A constant difference in the arrival time at two stations defines a hyperbola, and multiple stations provide multiple hyperbolas whose intersections define a source location. In order to take the advantage of both MDF and TOA technique, IMPACT (improved accuracy using TOA/MDF combined Technology) system has been developed and used world-widely [5].

The interferometry [6] technique is based on the fact that phase differences of lightning signal at an antenna array contain the information of the source position, which usually operates at VHF bands between tens and hundreds MHz . One interferometer gives the azimuth and elevation of the source, and two are able to add on the distance information.

There are also a few of approaches for locate lightning based on observations at a single station. The techniques basically use a single VLF receiver and give a more convenient way to locate the sources. The system [7] usually a combine the direction finding with estimation of the distance to the source strikes.

The simplest method to estimate the distance is based on the amplitude of lightning signal, which assumes that all lightning are the same and its amplitude decreases with distance [8]. The distance of the lightning strike also can be determined by the ratio [9] of the magnetics field to the electric field signals.

Wave line theory in waveguide is another method to get the distance of lightning. Full wave analysis [10] was used in order to examine the applicability of location technique. The technique was based on the observation of a couple of sequential pulses appearing on the waveform of each VLF sferics. From that, the information of both the direction and the distance can be determined.

Wave impedance [11] technique was used to measure the distance of nearby thunderstorm discharges in the Earth ionosphere. Wave interval is examined based on differences in the frequency dependencies of the static induction and components of electromagnetic field. Radio-wave reflection from waveguide walls is described by sferics of imaginary

The project has been supported by RDU100385, Universiti Malaysia Pahang.

sources of decreasing amplitude, which allows estimation of the near zone side which range about 50km.

The time-to-thunder [12] method was used to determine the lightning strike distance. The method used the combinations of broadband VHF antenna and microphone to form single-station detection. The broadband antenna was used to detect the electric field signals and the microphone was used to detect the acoustic signals. Based on the different time delay between both signals, the lightning strike can be calculated.

In this paper, the ratio of EMF to EF method was used to determine the lightning strike distance. The method used the combinations of wire antenna and magnetics loop antenna to form a single-station lightning distance determination. The experimental was conducted .In the method, the wire antenna was used to detect the EF signals and the magnetics loop antenna was used to detect the EMF signals. Based on the both signals, the lightning strike can be calculated.

II. MEASUREMENTS AND EXPERIMENT SETUP

A. Hardware development

The hardware to detect the Electric Field (EF) is a wire antenna. The antenna consists of 30cm copper wire, boost amplifier circuit, PVC protection housing and 40 meter of Mitti-75Ω coaxial cable. The main function of this hardware is to detect and amplify the (EF) signals when the lightning strikes to the ground. Fig.1 shows the overall of the single station detection system that has been installed at UMP Pekan.

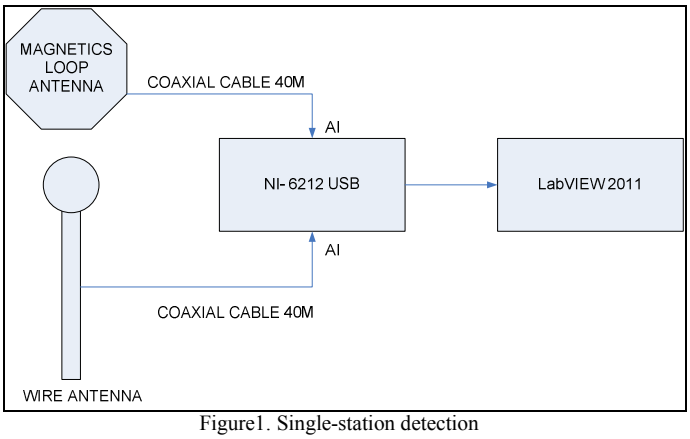

Figure1. Single-station detection

An amplifier circuit was used to amplify the signals detected by the wire antenna. This amplifier circuit is also consist element of protection to protect the system in case if high voltage or current pass through the receiver to the system. The Mitti-75Ω coaxial cable was used to connect the wire antenna to the DAQ- NI 6212-USB. This type of cable have relatively low resistance and suitable for transferring high speed signal without huge losses. Fig.2 showed the wire antenna has been installed at Block 1, Faculty of Electrical & Electronics UMP, Pekan.

Figure2. Wire Antenna to detect EF signals

Magnetics loop antenna was used to detect the electromagnetic fields (EMF) radiates when lightning strike. The antenna was placed on FKEE's building and connected to 40m coaxial cables. Both antennas have same length and specification of coaxial cables. Fig.3 showed the magnetics loop antenna installed at the site.

Figure3. Magnetics antenna to detect EMF

B. Software development

The graphical user interface (GUI) has been developed using National Instrument LabVIEW 2011 software. The GUI was developed to monitor the lightning activity at 25 km radius from Pekan. The signals will be filtered and analyze by the software programming. Time of detection, EMF and EF waveform signal, filter signals and estimated distance has been displayed the front panel of LabVIEW programming. Fig.4 showed the front panel of LabVIEW programming.

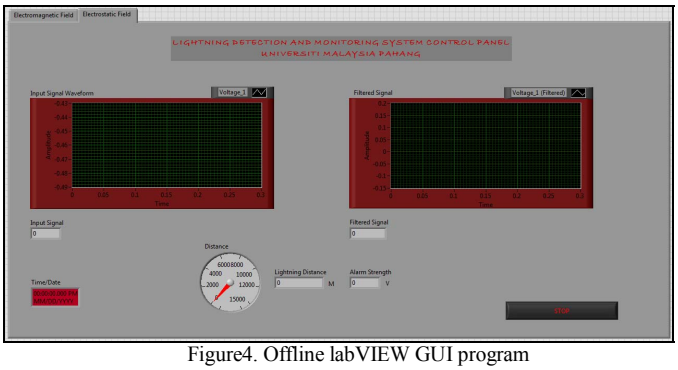

Figure4. Offline labVIEW GUI program

Fig. 5 shows the block diagram of programming structure to determine the lightning distance.

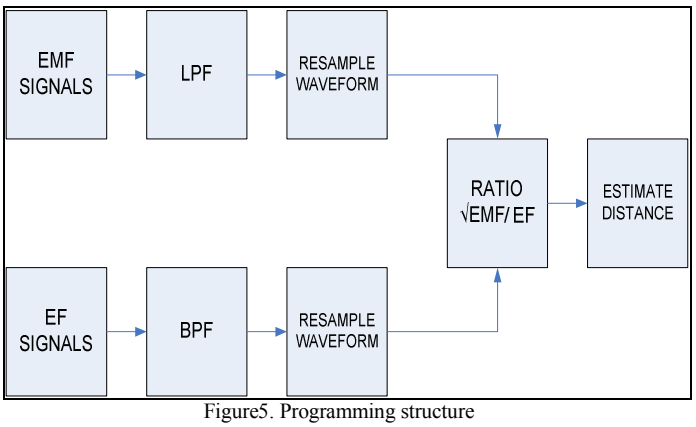

Figure5. Programming structure

A low pass filter LPF function in the LabVIEW programming was used to eliminate noise for EMF signals. The cut of frequency is 1 kHz for magnetics loop antenna. The EF signal was amplified and band-pass-filtered (BPF) was used in the frequency range between 1 kHz and 14 kHz. The lower cut off of 1 kHz is chosen to reduce the ham noise of the commercial power lines (50 Hz and harmonics), while the upper cut off of 14 kHz is used for anti-aliasing.

After filtering, the signal was then resampled again. The maximum peak reading for each signal was shown at the front panel of the GUI. Using the statistical function in LabVIEW the ratio of EMF to EF has been calculated and the lightning strike from the source can be estimated.

C. *Hardware interfacing*

The NI-USB 6212 type was used in this project. The function of this DAQ is to interface the hardware to personal computer where the hardware is the antennas. This DAQ have 16 analog inputs which is 16 bit with 400 kS/s for sampling data and powered by USB for high mobility. In these project two analog input channels has been used to detect the EMF and EF radiates from lightning discharge.

III. SINGLE-STATION DETECTION

A. *Estimation of distance*

Electric and magnetic fields generated by the lightning produced a signal having amplitude corresponding to the distance of lightning stroke. It has been determine that the distance of the lightning stroke within approximately 30 miles is directly proportional to the ratio of magnetics field to the electric field generated by the lightning stroke [10]. Equation (1) shows the formula to estimate the distance of the lightning stroke from the sensor.

$$Distance = \frac{\sqrt{H_\omega}}{E_\omega} \qquad (1)$$

Where H_ω is a horizontal magnetic fields and E_ω is vertical electric fields.

However, each magnetics loop antennas produces a voltage V_m which depends on the angle θ of the loop plane to the signal source, the frequency of observation ω, the loop area F, and the number of the turns n, according to the following formula:

$$V_m = \mu.H.\omega.F.n.\cos\theta \qquad (2)$$

B. *Estimation of direction*

From a pair of loop antenna that place perpendicular to each other, the direction of lightning strike can be estimated. The angle is determined by using this formula:

$$Direction = \tan^{-1}\frac{H_{NS}}{H_{EW}} \qquad (3)$$

Note that, the negative angle means the direction anti-clockwise from east direction. Figure 6 shows a pair of loop antenna schematic to find the direction of lightning strike.

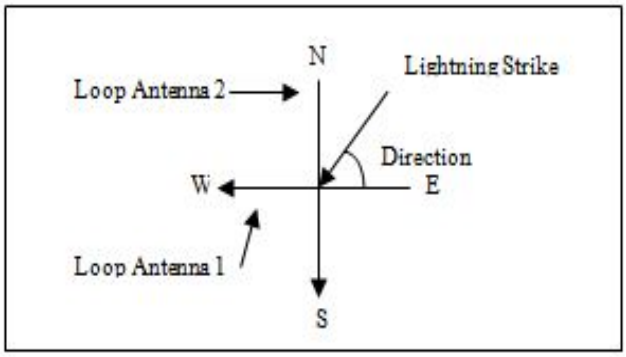

Figure6. A pair of loop antenna

IV. RESULT & DISCUSSION

This section describes the experimental results of lightning measurement using the ratio of EMF and EF. It includes results analysis and output that captured by the GUI LabVIEW software. In this project, the actual lightning strike distance has been compared to Pekan Lightning Detection System (PLDS).

The data of lightning strike detection was observed during thunderstorm days on 4th May 2012 at 8.15PM until 9.30PM. This data was captured by the system and the entire signal that observed in GUI was recorded. The data consist of the time of during lightning strike, EMF and EF amplitude. The data record as shown in Table 1.

Fig.7 shows the EF captured by the system for the negative return stroke occurred at 8.39pm on 4th May 2012. The positive value of EF indicates negative cloud to ground stroke.

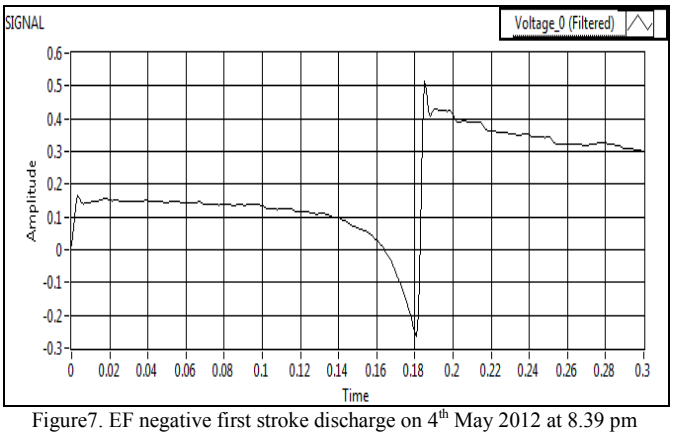

Figure7. EF negative first stroke discharge on 4th May 2012 at 8.39 pm

Fig.8 shows the positive return stroke occurred on 4th May 2012 at 8.55 pm. The value of EF recorded is -2.5 V/cm. Fig.9 shows the EMF measured by the system for the multiple negative return strokes occurred on 4th May 2012 at 9.03 pm.

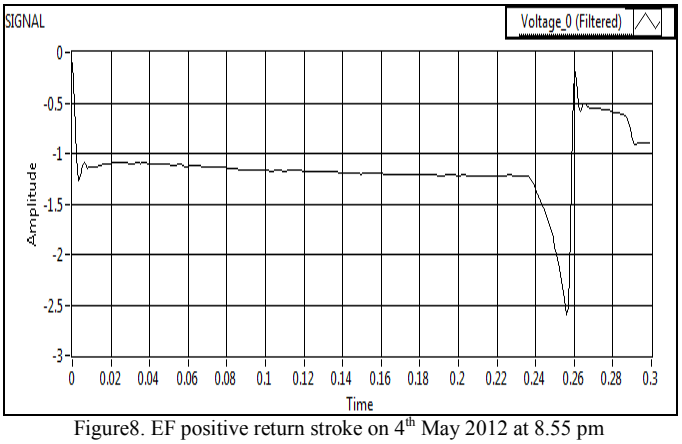

Figure8. EF positive return stroke on 4th May 2012 at 8.55 pm

The strength of EMF appears usually very small value of V_m compared to EF signals. A wire antenna is utilized to sense the EF produced by lightning stroke is a higher impedance device. That why the wire antenna produces higher voltage (V_m) than EMF antenna. The voltage produced by the loop antenna (EMF) signals appears usually as a very low impedance source because of technical difficulties to construct high loop inductances. That why the strength of EMF (V_m) is smaller compared to EF.

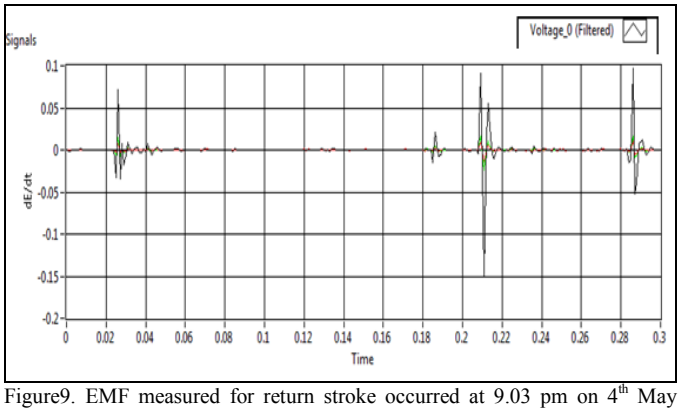

Figure9. EMF measured for return stroke occurred at 9.03 pm on 4th May 2012.

Table I showed the time of lightning occurrences, measurement of EF and EMF and calculated distance. The distance to the lightning stroke within approximately 30 miles is directly proportional to the ratio of EMF to EF generated by the lightning stroke. The distance can be calculated using equation (1). The shortest distance was recorded at 8.44.18 PM which is 0.19 km from the sensor to the lightning stroke. The strenght of EF is equal to 4.2 V/cm and 0.65 V/cm for EMF.

Table II showed the detection comparison between the single station detection with Pekan Lightning Detection System (PLDS). The sensor was located on coordinate 3° 32' 0" North, 103° 28' 0" East which is Block 1, FKEE, Universiti Malaysia Pahang, Pekan. The system consists of three major parts, including the combination of magnetic direction and time –of- arrival finder antenna, receiver and lightning location information analysis and GUI system.

TABLE I. LIGHTNING EF , EMF AND DISTANCE OF STRIKE ON 4TH MAY 2012.

Time (PM)	EF Amplitude (V_m)	EMF Amplitude (V_m)	Estimated Distance (KM)
8.39.10	0.5	0.15	0.77
8.43.22	1.0	0.25	0.5
8.44.18	4.2	0.65	0.19
8.45.39	1.2	0.32	0.47
8.55.31	-2.6	0.45	0.25
8.56.44	0.5	0.13	0.72

9.02.12	0.55	0.18	0.77
9.02.25	-0.27	0.1	1.17
9.03.39	0.2	0.08	1.41
9.26.14	-0.4	0.15	0.97

Lightning data was obtained from the PLDS's panel for the period between 8.10 pm and 9.30 pm at 4th May 2012. The data was for a region 10 km radius from FKEE. Fig.10 shows the raw lightning data from PLDS. The system has successfully detected the location of the lightning stroke.

TABLE II. DETECTION COMPARISON WITH PLDS

TABLE III.

Time (PM)	No. of Lightning Detected	
	Single Station Detection	PLDS
8.39	1	3
8.43	1	2
8.44	1	3
8.45	1	2
8.55	1	3
8.56	1	3
9.02	2	5
9.03	1	2
9.26	1	2

Data from table II shows the comparison of the lightning strikes recorded by PLDS and single station detection. Five strikes were recorded by PLDS at 9.02 pm and 2 strikes were recorded by single station at same time. As a whole, the total of lightning strikes detected by PLDS is 25 strikes and 10 lightning strikes were detected by single station. The detection of PLDS is very high because PLDS used Magnetic Direction Finder and Time -of- Arrival method of detection.

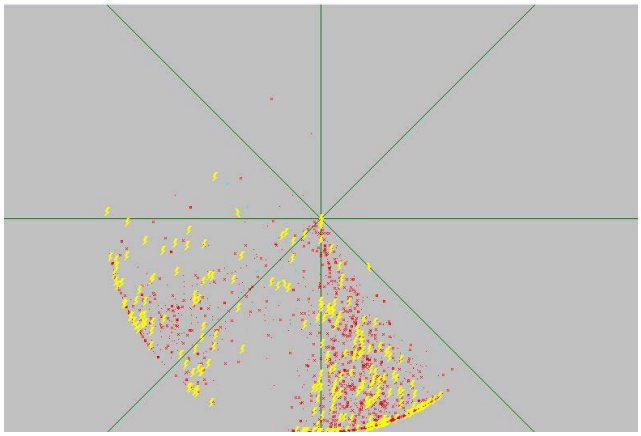

Figure10. Raw lightning data 20 km radius from FKEE UMP Pekan captured by PLDS

V. CONCLUSIONS

A simple technique used to determine the lightning strike by measuring the EMF and EF during on the thunderstorm days has been described. The experiment has been conducted at campus Pekan , Universiti Malaysia Pahang, to collect the lightning data. The detection range for single station is up to 10 km radius based on data collection during March 2012 to May 2012. The detection accuracy almost 80 percent and has been validated by PLDS. However the percent of detection accuracy has been decreased to 40 percent if the range detection increases up to 20 km radius.

ACKNOWLEDGMENT

The authors wish to thank to Universiti Malaysia Pahang that made this research possible. The project has been supported by RDU100385.

REFERENCES

[1] E. P. Krider, R. C. Noggle and M. A. Uman, A gated, wide-band, magnetic direction finder for lightning return strokes, J. Appl. Meteor., Vol. 15, pp. 301, 1976.

[2] P. W. Casper and R. B. Bent. Results from the LPATS USA National Lightning Detection and Tracking System for the 1991 Lightning Season. The 21st International Conference on Lightning Protection, Berlin, Germany, 1992, 22-25

[3] D. Fayan, and R. Meier, "*Intelligent Time-of-Arrival Estimation*", IEEE Forum on Integrated and Sustainable Transportation System (FISTS), 2011.

[4] K. Michishita, Y. Hungo, and S. Yokoyama, "*Estimation of Lightning Striking Points by Time-of-Arrival Method with Small Network*", X Int. Sym. on Lightning Protection (XSIPDA), Nov 2009.

[5] K. L. Cummins, M. J. Murphy, E. A. Bardo et al., A combined TOA/MDF technology upgrade of the US national lightning detection network. J. Geophys. Res, 1998, 103(D8): 903-904.

[6] P. Richard and G. Auffray, VHF-UHF interferometric measurements, application to lightning discharge mapping. Radio Science, 1985, 20(2):171-192.

[7] V. A. Rafalsky, A. P. Nickolaenko, A. V. Shrets, and M. Hoyakawa, "*Location of Lightning Discharges from a Single Station*", Journal of Geophysical Research, Vol. 100, pg 20, 829-20, 838, Oct 20, 1995.

[8] V. Ramachandran, J. N. Prakash, A. Deo and S. Kumar, Lightning stroke distance estimation from single station observation and validation with WWLLN data, Ann. Geophys, 25, 1509–1517, 2007.

[9] Lothar H. Runhke, Boulder, Colo. "Determining Distance to Lightning Strokes from a Single Station. United Stated Patents 3715660, Feb.6, 1963

[10] W. Itaro, I. Nagaro, S. Yagatani and M. Ozoki, "*Lightning Location with Single-Station of VLF Sferics*", 2nd Karazawa Workshop, WAVE 11 pg. 22, March 2006.

[11] M. A. Karol and A. P. Nikolaenko, "*Measurement of Distances to Nearby Thunderstorm Discharges*", Radio Physics & Quantum Electronics, Vol. 36, Nov 3-4, 1993.

[12] W.I.Ibrahim, Zulkurnain Abdul Malek, " Time to thunder method of Lightning Distance Determination", 2010 IEEE International Conference on Pewer and Energy (PECon)