A SYSTEM FOR THE ADVANCE WARNING OF RISK OF LIGHTNING

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Abstract: *The design and performance of a system is described to provide advance warning of the risk of local lightning on the basis of observations of atmospheric electric field, radio noise and lightning impulse signal activity. The values of these parameters are assessed to provide two levels of warning.*

1. INTRODUCTION

A need for advance warning of the risk of the local occurrence of lightning arises in many practical situations. Various warning systems have been devised over the years. Some use radio signal monitoring to track the actual occurrence of lightning events geographically, others try to measure local conditions at which lightning is likely. And meteorology can predict when atmospheric conditions are likely to be suitable for the formation of thunderclouds. There remains need for warning when local conditions at particular locations are such that lightning is likely to occur within a few tens of minutes. Such warnings are needed to enable lightning sensitive operations to be closed down and personnel protected.

The present paper describes the design and performance of a lightning warning system that replaced an old Nitro Nobel Lightning Forecasting System VSL 2. The new system was constructed for use in particularly adverse weather conditions with emphasis more on practical system operational features and reliability than on fundamental aspects of warning philosophy. The versatility of the system developed allows easy changes to warning criteria in the light of practical experience.

2. BASIS OF LIGHTNING WARNING

Warning of the local risk of lightning activity is based on simultaneous observations of the ambient atmospheric electric field, the radio noise in a fairly narrow frequency band centred on 27 kHz and the rate of occurrence of impulse signals over a frequency band of 2-200 kHz. Radio noise at 27 kHz and impulse signals within the 2 to 200 kHz frequency band indicate the level of lightning activity around. Low frequency radio signals travel around the world with fairly low attenuation. Lightning activity can hence be detected at large distances. A threshold amplitude provides a simple way to restrict interest to relatively local events. Ambient atmospheric electric field measurements provide very localised indication of the electrostatic conditions at which lightning can occur and propagate to the earth surface.

The warning system developed comprises a sensor unit that is mounted at a suitable out of doors location and cable linked to a microcomputer in a nearby building for all the analysis, display, risk interpretation, warning presentation and continuous recording of observations. The overall system is shown in Figure 1 below.

The processing of the radio impulse signals from the sensor unit involves interpretation in terms the number of events with less than 100s between them above a set amplitude and outside a set small time frame that distinguishes single from restrike lightning events. Risk levels are assessed from electric field, radio noise and the occurrence of radio impulse signals to the following criteria with the alarm status levels displayed by green, amber and red lights on the base unit equipment and shown by matching colour traces on the computer display and data recordings.

Green: No risk & system operating normally

Amber: Four alternative risk criteria:
1) (Electric field E > 1.5 kV m^{-1}) & (Noise > Noise threshold)
2) (Noise > Noise threshold) & (1 lightning event)
3) (Electric field E > 3 kV m^{-1})
4) (2 lightning events < 100s)

Red: Five alternative risk criteria:
1) (Electric field E > 1.5 kV m^{-1}) & (Noise > Noise threshold) & (1 lightning event)
2) (Noise > Noise threshold) & (2 lightning events < 100s)
3) (Electric field E > 3 kV m^{-1}) & (1 lightning event)
4) (3 lightning events < 100s between successive events)
5) (Electric field E > 4.5 kV m^{-1})

3. METHODS OF MEASUREMENT

3.1 Introduction

The sensor unit of the warning system comprises an electrostatic fieldmeter, suitable for continuous operation in adverse environmental conditions, mounted on top of a 2m tall 50mm diameter antenna tube which picks up radio noise signals (at 27kHz) and lightning impulse signals (over the band 2-200kHz). The antenna tube is insulated from the sensor unit and the base mounting. The sensor assembly is shown in Figure 2 below.

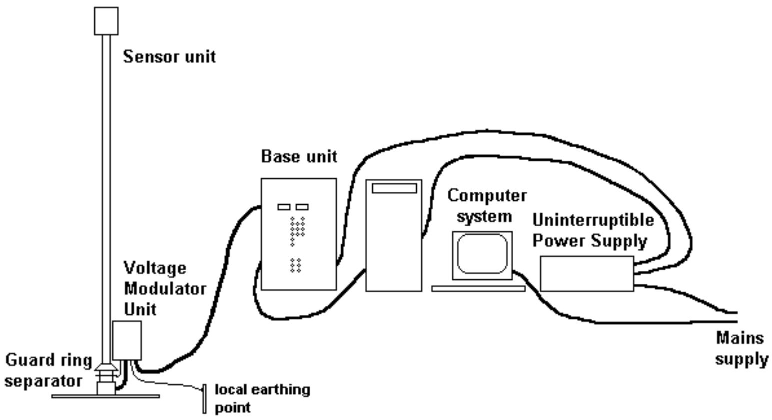


Figure 1: Overall system arrangement

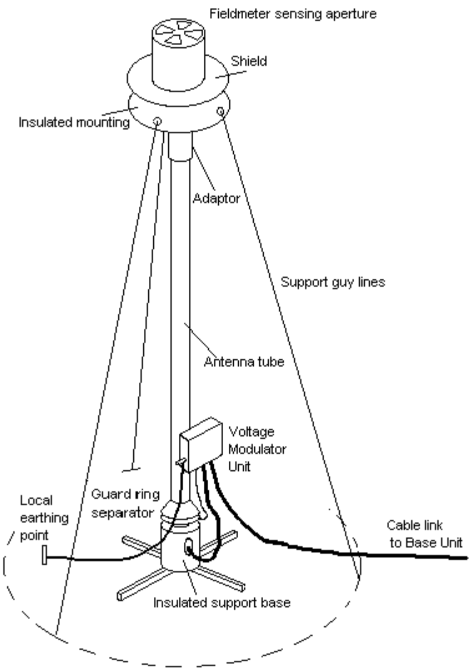
3.2 Atmospheric electric field measurement

The atmospheric electric field is measured by an electrostatic fieldmeter acting as a potential probe at a known height above ground level. All the power supply and signal processing circuits, for the sensor unit and the base unit, are isolated from earth with an insulation capability to over 1 kV. With this isolation the fieldmeter can be directly calibrated in situ in terms of local voltage. With the known probe height above ground, the ambient electric field is hence known in volts per metre. The advantage of the pole mounting arrangement for electric field measurement is simplicity of mounting, the avoidance of interference by ground level dust and debris and the enhancement of the effective sensitivity of the electric field measurement capability.

Sometimes it may be necessary to mount the fieldmeter sensor either near structures that may perturb the local ambient atmospheric electric field or on hills or buildings. In such situations electric field observations may be normalised by reference to observations under clear sky conditions.

The fieldmeter part of the sensor unit was based on well tried proprietary design features [1] with physical design features (large gaps and long insulation tracking paths) based on previous experience of overcoming problems of fieldmeter operation in wet environments [2]. The sensing aperture of the fieldmeter was arranged to look directly upwards. This gave simplicity of mounting and opportunity for rain to wash away any atmospheric dust and debris from the sensing surfaces. For the particular application location there would have been little benefit to the design of the sensing system by alternative mounting alignments to provide adequate environmental immunity because high local winds would ensure water penetration into any open structure.

Figure 2: Sensor Unit features



3.3 Radio noise and impulse observations

Radio noise and lightning impulse signals are picked up by the electrically isolated antenna tube used to mount the fieldmeter above ground level. These signals are processed on circuits mounted within the casing of the fieldmeter. The 2 to 200 kHz passband is defined by separate high pass and low pass Salen and Keys type filter circuits. The 27 kHz 0.5kHz passband channel is defined by a 4 pole Butterworth filter with a Q around 55. The dynamic range of radio noise and impulse signal observations is extended using decade switched gain stages before precision signal rectification. Peak detection and hold circuits (20 ms) are used to enable digitisation, serial communication and software analysis to make accurate measurement of signal peak amplitudes.

3.4 Operational health monitoring

A particular feature of the sensor system is the inclusion of continuous ‘operational health monitoring’ facilities for all three observation channels. For the fieldmeter the voltage of the whole sensor assembly is modulated, under software control, relative to local earth potential by a low frequency (about 0.5Hz) square wave of about 40V peak to peak. To avoid influence by any electrical leakage over the insulator mounting the bottom end of the antenna tube in very wet conditions it was found advantageous to also apply the voltage modulation signal to a guard ring shield in the bottom end insulator of the antenna tube.

Software analysis of fieldmeter observations takes note of signal levels just prior to and just following modulation so that compensation can be made for linear changes in electric field measurements. Observations are averaged over a few hundred modulation cycles before indication is given of any unsatisfactory operational health condition. For the two radio channels, internal noise signals are generated of set amplitude and these are switched on and off under software control at about 0.1Hz. The observed modulation of the fieldmeter and radio observations are compared to the values expected and if these fall below set fractions then individual health warnings are indicated and recorded. This approach is particularly appropriate for confidence in warning capability in adverse environmental conditions.

3.5 Signal processing

Measurement of the intensity and polarity of the electric field and of the amplitude of the radio noise and lightning impulse signals by the Sensor Unit are multiplexed into a 12 bit ADC. These signals are communicated via an opto-isolated RS232 link at 133 sets of readings each second to a nearby microcomputer for analysis, display and data recording. Software processing of signals from the Sensor Unit interprets these as observed ambient atmospheric field values in volts per meter or μV or mV for the radio signals. These are used, displayed and stored as such. Software feedback to the sensor unit controls the setting of the sensitivity of the fieldmeter (4 decades of adjustment) and of the radio noise and lightning impulse signals (1 decade of adjustment each). It also controls application of the signals involved in operational health monitoring.

3.6 Displays and data storage

System observations are displayed on the colour monitor as graphs of electric field, radio noise level and lightning impulse occurrence versus time. Additional traces show operational health of each observation channel and the interpreted lightning warning status. These observations are held in a large ring buffer providing opportunity for direct roll back for inspection of earlier records. Observations are stored on the hard disc and also stored to an external large capacity recording medium for long term back-up and possible separate analysis. Overall storage space is minimised by averaging data over longer intervals while signals remain below user set levels.

4. PERFORMANCE FEATURES

Measurement of ambient electric fields is made in 4 decades of sensitivity 0.1, 1, 10 and 100 kV m^{-1} full scale. Measurements can be made to better than 1% of scale. The alarm threshold level for radio noise corresponds to a charge of 2.2 pC induced on the 2 m antenna within a 500 Hz bandwidth at 27 kHz. The alarm threshold level for impulse signals corresponds to a charge of 315 pC induced on the antenna within a 2 to 200 kHz bandwidth. Both radio channels have a dynamic range about 46dB above background noise. This provides very adequate dynamic range within which threshold levels may be set.

The system described has been in full and continuous operation for over 18 months on the island of St Kilda. (This is a small rocky island about 40 miles north west of the Scottish Outer Hebrides with very inclement waether conditions!). Good correspondence of warning indication to local conditions has been noted.

5. FURTHER ENHANCEMENTS

Radio observations could be enhanced for noise and in particular for impulse signals by use of DF loop type antenna and signal processing arrangements. If signals are observed to come mainly from a particular bearing direction and if the bearing does not change, then the source will be approaching or retreating from the point of observation.

Taking differences between four fieldmeters mounted at compass bearing points would give information on north-south and east-west horizontal components of electric fields. Combination of these with the averaged vertical component will give a directional vector to the effective center of charge responsible for the observations. Spreadsheet modelling calculations indicate that the bearing and angular location of typical thunderclouds should be able to be tracked out to 10-15 km.

6. CONCLUSIONS

Design and performance features of a system providing advance warning of the local risk of lightning have been described. The system has proved its ability to provide continuous warning capability even in very adverse weather conditions. A particular feature of the system is the inclusion of continuous operational health monitoring.

REFERENCES:

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