N91-32617

'GHTNING LOCATION SYSTEM SUPERVISING SWEDISH POWER TRANSMISSION NETWORK

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ABSTRACT

For electric utilities the ability to prevent or minimise lightning damage on personnel and power system is of greatest importance. For these reasons Vattenfall, the Swedish State Power Board, has been utilising data since 1983 from a nation-wide lightning location system (LLS) for accurately locating lightning strikes to ground.

Lightning data is distributed and presented on colour graphic displays at regional power network control centres as well as at the national power system control centre for optimal data utilisation.

Main objectives for Vattenfall's utilisation of LLS are:

- **Supervising of the power system for optimal and safe utilisation of the transmission and generating capacity during periods of thunderstorms.**
- **Warning service to maintenance and service crews at power lines and sub-stations to terminate operations hazardous when lightning.**
- **Rapid positioning of emergency crews to locate network damage at areas of detected lightning.**
- **Post-analysis of power outages and transmission faults in relation to lightning using archived lightning data for determination of appropriate design and insulation levels of equipment.**

Staff at the supervisory control centres have found LLS extremely useful and economically justified since the availability of the power system has increased as well as the level of personnel safety. Comprehensive experience has been obtained regarding integration of LLS lightning data and LLS system to ordinary operations routines and standard equipment at control centres.

INTRODUCTION

In recent years, considerable progress has been made in the field of lightning research, the practical results being reflected by today's highly-developed protection and warning systems. However, the rapid pace of modern technological development constantly produces new demands for protection against lightning which, in combination with demands for higher safety, necessitates further development work in several fields. An automatic lightning location system (LLS) may be of major importance in various areas of industry, commerce, and municipal activities in reducing the incidence of lightning damage to property and plant, and in minimising human injury.

Electrical transients associated with lightning represent a major injury hazard to personnel working on high-tension lines and sub-stations. Accidents of this nature (some with fatal results) are reported every year. Reliable lightning warning systems would greatly increase personal safety and reduce maintenance costs.

The main transmission network can be made less vulnerable by modifying the pattern of generation so as to increase the tolerance of the system to line outages such as occur during thunderstorms. However, since this implies that the grid is not used in the optimum manner, this type of rescheduling should be carried out only when the risk of lightning is present. High-tension subscribers, such as process industries, who are particularly susceptible to power failure can use their own (albeit expensive) in-house facilities to supply sensitive, high-priority loads at periods of high risk. Reliable advance warning of electrical storms by lightning detection systems would be of major financial benefit in both of these cases.

More detailed information received by lightning location systems regarding current and approaching thunderstorms would enable plant operations and power production to be scheduled in a manner which might enable loss of supply to be avoided.

Lightning striking an inadequately protected electrical installation will usually cause a power interruption of a lesser or greater duration, due to disruption of the remote control system or because of damage to a plant component. The consequences of such faults are often difficult to evaluate, the cost of a power failure being dependent both on the category of subscriber and of the duration of the interruption. Improved thunderstorm and lightning statistics collected by lightning location systems can be used to develop a financially optimised system of lightning protection, enabling the period of disruption to be reduced by adopting precautionary measures during the most hazardous weather conditions.

As example, transformers used in power distribution networks are particularly vulnerable to lightning. In Sweden, a large number of transformers is destroyed annually, adding considerably to the costs incurred by the utilities. Further damage is suffered by other electrical installations, high-tension and low-tension cabling, insulators, circuit breakers etc., causing major financial losses. The resultant disruption of power supplies also causes financial loss in terms of lost production etc. Accurate and reliable lightning data from LLS for investigating correlation with statistics of faults and outages in the power systems would probably result in better and safer insulation standards and coordination for improved protection.

Other areas in which lightning detection systems may provide valuable information include the public meteorological service, telecommunications, national air forces, civil aviation, forest fire protection, process industries, the maintenance of high masts, blasting operations, offshore drilling operations, oil platforms etc.

REQUIREMENTS

Information regarding thunderstorms and lightning discharges is of vital importance to Vattenfall in the following main areas:

- For day-to-day system operations and the reporting of imminent thunderstorms.
- To ensure the safety of personnel engaged in work on transmission lines and sub-stations.
- To locate damage caused by lightning in transmission and distribution power networks.
- For the retrospective investigation of grid faults and disturbances.

Prior to the utilisation of the LLS network, information on current and approaching thunderstorms was generally obtained as follows:

Firstly, the national power system control centre received forecasts from the Swedish Meteorological Institute (SMI) by telephone. During the thunderstorm season (May to September inclusive), forecasts were supplied every morning followed, if the weather situation is changing, by a new forecast during the day. At other times of year, forecasts were supplied only as required by the weather situation. The National Control Centre transmitted the forecasts to the local and regional power network control centres.

Secondly, manned power and transformer stations supplied information to the local and regional control centres regarding the presence of thunderstorms and their passage through the particular area. The local and regional control centres, in turn, informed the National Control Centre and other control centres in areas which may conceivably be affected by the weather system.

These information channels suffered from obvious defects, both individually and as a combination. For instance, forecasts were and still are based on analysis of meteorological data f.i. from weather radar and satellite pictures, which gives good information on clouds and precipitation but cannot display or locate lightning. However, the most disturbing aspects from the Vattenfall's viewpoint was the trend from manually-operated to automated, remotely-controlled power and transformer stations, a development which had greatly reduced the number of manned installations in recent years.

Furthermore, both the Vattenfall's own regions and those of other power utilities reported that the centralisation of personnel resources brought about by the commissioning of regional operations monitoring systems and other such facilities is such that it will not be possible, in future, to undertake the reporting of electrical storms in the manner required.

The workers unions had strongly commented on the hazards involved in transmission line and switching station work resulting from the fact that the reporting system no longer provided countrywide coverage and that the system was not as accurate as in previous years. Reports dealing with this aspect had emphasised the need to provide replacements for the existing manual reporting procedures.

Although SMI forecasts usually provided indications as to the likelihood of lightning, information regarding current electrical storms was the type mainly used as a basis for determining whether or not to commence or to terminate transmission line and switching station work; for assessing the need for modifying the pattern of generation in a major network and, in the case of large, vulnerable subscribers such as process industries, etc., for deciding whether or not to switch high-priority systems to independent supplies. However, unexpected events may occur in view of the inherent uncertainty and susceptibility to error or forecasts. Since thunder and lightning may occur despite an optimistic forecast, correct information regarding current or imminent thunderstorms is of particular importance.

Furthermore, the frequently incomplete and inexact type of information available made it extremely difficult to establish in which cases lightning had been the true cause of operational disturbances and plant faults. In most cases, it was possible only to state whether or not this may have been the likely cause.

In view of the foregoing, it was natural to try to supplement existing systems and, in the long term, also to provide a replacement for at least the manual reporting procedures.

LLS NETWORK DEVELOPMENT

Vattenfall has been supporting research and development of a nation-wide lightning location system (LLS) network for locating lightning strikes to ground. A joint project was commenced in 1983 in cooperation with the Institute for High Voltage Research (IfH) at Uppsala, Sweden. IfH had been running a network of LLS in the southern part of Sweden since the end of the 1970's for research purposes with interestingly good results.

LLS is a computerised data aquisition system that employs electro-magnetic pulses from lightning for real-time calculation and determination of the position of cloud-to-ground lightning strokes. The ground strike point is plotted on a map on a multi-colour graphic display for accurate visual presentation. Information includes lightning polarity, amplitude and multiplicity.

The LLS manufactured by Lightning Location & Protection (LLP) Inc. has been commercially available on the market for more than a decade so no detailed technical presentation of the system will be given in this paper. The schematic system function is described in a block diagram in ***Figure 1***.

The LLS equipment consisted at that time of four Direction Finders (DF) and a central computer, the Position Analyzer (PA), real-time processing the lightning data received from the DF's. Lightning data from the LLS network was presented in real-time on multi-colour displays and multi-colour hard-copy units at Vattenfall's National Control Centre for the power system. All data communication were established via dedicated telephone lines. On the map in ***Figure 2*** the locations of the original DF's can be noted.

Identical LLS network was operated in Norway and in Finland and Denmark there were plans to install similar systems. In these countries the electric utilities had been playing a major role in supporting and funding development of national LLS. Integration of the systems in all four Nordic countries into one large systems would probably lead to several advantages, f. i. cost reduction, larger geographical area of system coverage, etc. Increased system availability will also be the result of an integrations since a large number of DF's provide for a high level of mutual redundancy.

After the first couple of years of utilisation of lightning data at Vattenfall it became quite clear that the number of DF's was much too small to give an altogether appropriate geographical coverage by the LLS. Engineers at the power network control centres wanted such a LLS coverage so all the main 400 kV transmission lines could be supervised during thunder and lightning. This called for an expansion of the system to seven DF's which was completed in 1986. Another expansion including one extra DF station was made in 1988. DF sites of today in Sweden and in the other Nordic countries are presented in ***Figure 3***.

During the same period communication links were set up with the Norwegian system, the completed Finnish system and later the Danish system for real-time integration of the systems when desired. A special committee worked out recommendations for a total integration of the Nordic systems which called for a large-scale substitution to a new generation of equipment designed for packet-switching data communication in order to reduce the data transmission costs. Using data transmission via packet-switching data network instead of dedicated telephone lines will reduce the transmission cost in the inter-Nordic LLS network by 50 to 80 percent depending on country. Due to the high costs of a total substitution of equipment it was decided that each country would care for its own time schedule for system up-grading regarding data communication development and economical aspects.

The last couple of years the Nordic LLS network have been partly interconnected i.e. the Swedish LLS network has been able to utilise real-time data from some Norwegian and some Finnish DF stations and the LLS systems in Norway and Finland have been connected to certain Swedish DF stations. This test-integration has proven successful and has provided interesting results and will probably be made permanent during 1990 or 1991. These integration tests were carried out using dedicated telephone lines or dial-up telephone connections. When integration is going to be permanent a packet-switching data communication network will be utilised.

In Norway a technique was developed for presentation of real-time lightning data on ordinary personal computers with multi-colour graphic displays. This was a major contribution for low-cost distribution of lightning data to several locations within the organisation and to companies with limited financial resources. Vattenfall sponsored this development since experiences of the the original display units were not satisfactory mainly because of lacking in proper handling routines for control centre environment.

Basic demands for data presentation equipment to be used in power system control centres are that all information displayed on monitors should be quite clear and easy to understand. The equipment has to be extremely simple to use. In a situation where a major outage or disturbance in the power system has occurred there are no time for misunderstandings or mistakes in equipment management. Everything has to run smoothly in order to carry out the major task to rearrange the power network as fast as possible. The system must provide clear, unambiguous indications which preclude the possibility of misinterpretation and should require a minimum of operation. Instrumentation must be kept to the absolute minimum. Of these reasons it is of great importance to be able to customise presentation and handling routines on ordinary personal computers suitable for specific needs and utilisation.

UTILISATION AND EXPERIENCE

The Vattenfall personnel have long been aware of the limitations of the old manual lightning reporting system. As a result, the development of automatic detection systems has been followed with intense interest by Vattenfall.

A simple test link with the LLS system was established and evaluation of the test showed that the results were excellent. The LLS system was greatly superior to the Vattenfall's existing reporting system in terms of coverage, accuracy and efficiency. The LLS tests indicated that the old manual system of observation stations was inadequate.

Access to lightning information supplied by the LLS system in real time is considered by the National Control Centre to be extremely valuable, especially in view of the opportunities which this would afford in terms of issuing sufficient advance warning to service crews working on the grid, and of the facility of rescheduling operations to minimise the incidence of system faults.

Presentation units and associated multi-colour video displays and hard-copy units were purchased and installed immediately adjacent to the normal control operators work stations at the National Control Centre to enable the operators to observe the lightning information displayed on the VDU's with complete ease and to minimise the problems of operating the equipment as far as possible. The equipment was connected to the LLS network by a dedicated telephone link. During the first couple of years the presentation equipment was the old type of original Remote Display Processors from LLP Inc, so called RDP's. Nowadays Vattenfall is using ordinary personal computers with multi-colour graphic displays as presentation units. This solution calls for qualified soft-ware development but is still favourable economically.

When a lightning discharge is recorded by the system, the presentation unit emits a high-pitched audible alarm and a red lamp commences to flash. The strike point is indicated on the screen by a cross or square depending on the polarity, and the coordinates of the point are displayed simultaneously at the bottom of the screen. Typical displays are shown in ***Figure 4***. The operator records the area in which the discharge has taken place, and can use the controls to select a more detailed map to identify the strike point more accurately. The operator is then in a position to inform the local control centres in question of the electrical storm and to correlate simultaneous power system faults directly with the strike. This procedure greatly facilitates and accelerates the implementation of corrective measures such as the restoration of supplies, rescheduling of operations, fault tracing, starting of stand-by generation plant, etc.

The provision of the presentation unit with a memory for storing lightning data facilitates the subsequent investigation of whether or nor lightning has been the cause of system disturbances. This is done by redisplaying the lightning data for the particular period on the screen and studying the thunderstorm activity, if any in the particular area.

Having been in service for some years the general impression among operating personnel following the utilisation of LLS data and the display systems is that the equipment is a valuable addition to the other monitoring systems installed in the National Control Centre and local and regional control centres, and that more detailed and reliable information than hitherto regarding thunderstorms and lightning discharges would be of major benefit.

It has been established that the LLS system has provided the National Control Centre with considerable more information regarding lightning phenomena than the earlier manual reporting procedures. On occasions, having observed and reported lightning strikes to the local control centres in the areas affected, the National Control Centre system supervisor has found that staff at these centres have been unaware of the presence of thunderstorms in their areas. These situations may have been due to the deficiencies of the existing manual reporting system as already described.

The inevitable degree of uncertainty inherent in the SMI lightning forecasts, as demonstrated by the occasions on which the LLS system unit has recorded lightning in areas assigned a forecast of low lightning risk, may also be noted. There are several examples on occasions where LLS system monitors have reported lightning discharges along transmission lines, the strikes being accompanied by earth fault indications on the lines. No lightning reports were received from the field, while the forecasts for the areas indicated low risk of lightning.

The fact that the presentation unit displays lightning information in real-time is a major advantage which allows the operator to follow the course of an electrical storm across the country enabling him to predict the areas which will be affected. On such occasions, operators have been able to issue advance warnings to the various districts, thereby allowing line work to be deferred, unsuitable operations schedules to be revised, standby plant to be started or kept in service, etc. Operators have stated that they now work in a somewhat different manner than heretofore now that the lightning information is available in an easily comprehensible manner. "Being continuously aware of the lightning information, we are now more careful to avoid certain operating decisions which we would take under normal circumstances, but which appear less appropriate when thunderstorms are in the offing."

The following example illustrates the favourable economic consequences of utilising data from the LLS network and how control centre personnel make use of the data presented. From time to time the transmission network is scheduled for transmitting power generated by hydro power stations in the north of Sweden to the south of Sweden and to Denmark. For safety reasons power transmission is accepted only up to a certain level in case of lightning striking one of the transmitting lines causing extreme transmission load on the intact lines which might lead to severe network instability and a major outage with far-reaching consequences. At these occasions the engineers and supervisors at the National Control Centre have been able to increase the transmitted power considerably since they can keep track of existing and imminent lightning by using data from the LLS network making sure there is no risk of lightning approaching the vulnerable transmitting section. If the LLS network records lightning in the vicinity of the transmission lines the control centre supervisors immediately order a rapid decrease in the level of power transmission according to the safety standards. If the transmission had not taken place the power would normally have been generated locally by oil-fired power plants. Since producing electric power in oil condense power plants is much more expensive than producing the power in hydro power plants, it is of great economical interest to transmit as much low-cost hydro power as possible substituting power using oil. At one specific time, transmission at a higher level of 1000 MW could continue for 24 hours since the power network was supervised by utilising lightning data thus during this short period creating a profit exceeding US$ 100 000 compared to the alternative of producing the power locally by using expensive fuel.

CONCLUSIONS

In summery, it may be said that the installation of presentation units and display systems at the National Control Centre and at other control centres and their connection to the lightning location system has proved to be a valuable aid to improved and more reliable operations management and supervision. The equipment is also appreciated by the personnel, although it has naturally suffered from the invariable teething troubles in the early days. However, it would appear that since the change to the PC based display systems the operators and the control centre supervisors are very much in favour of the equipment and the utilisation of lightning data in transmission network operation and supervision.

Vattenfall is aware that the system has not yet achieved its optimum accuracy and efficiency. However, it is not until in this present situation when Vattenfall has acquired an sufficient insight into the potential of the system, it would be of interest to undertake a careful expansion of the LLS network so that the deficiencies of the system might be studied in closer detail and, hopefully, eliminated. Discussions with the users have indicated that there is considerable interest in expanding the existing LLS network by the installation of further units, provided that new equipment should be installed in a way and by a schedule which will meet the requirements of the users to the greatest possible extent.

To conclude, the LLS has proven to have a high degree of availability, to have increased the level for personnel safety and to have been quite profitable.

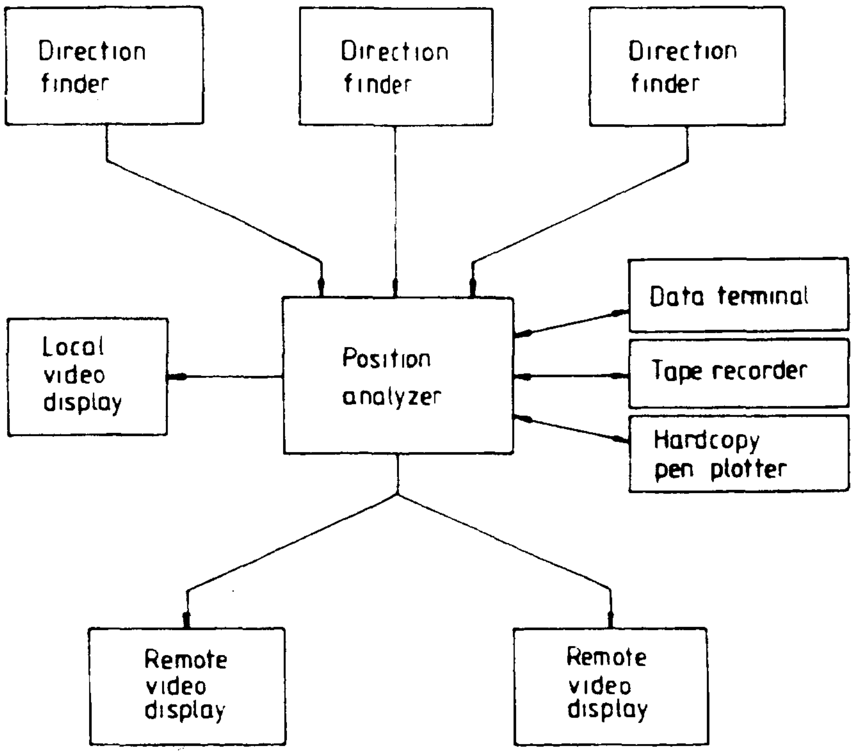

Figure 1. **Block diagram of the basic LLP lightning location system**

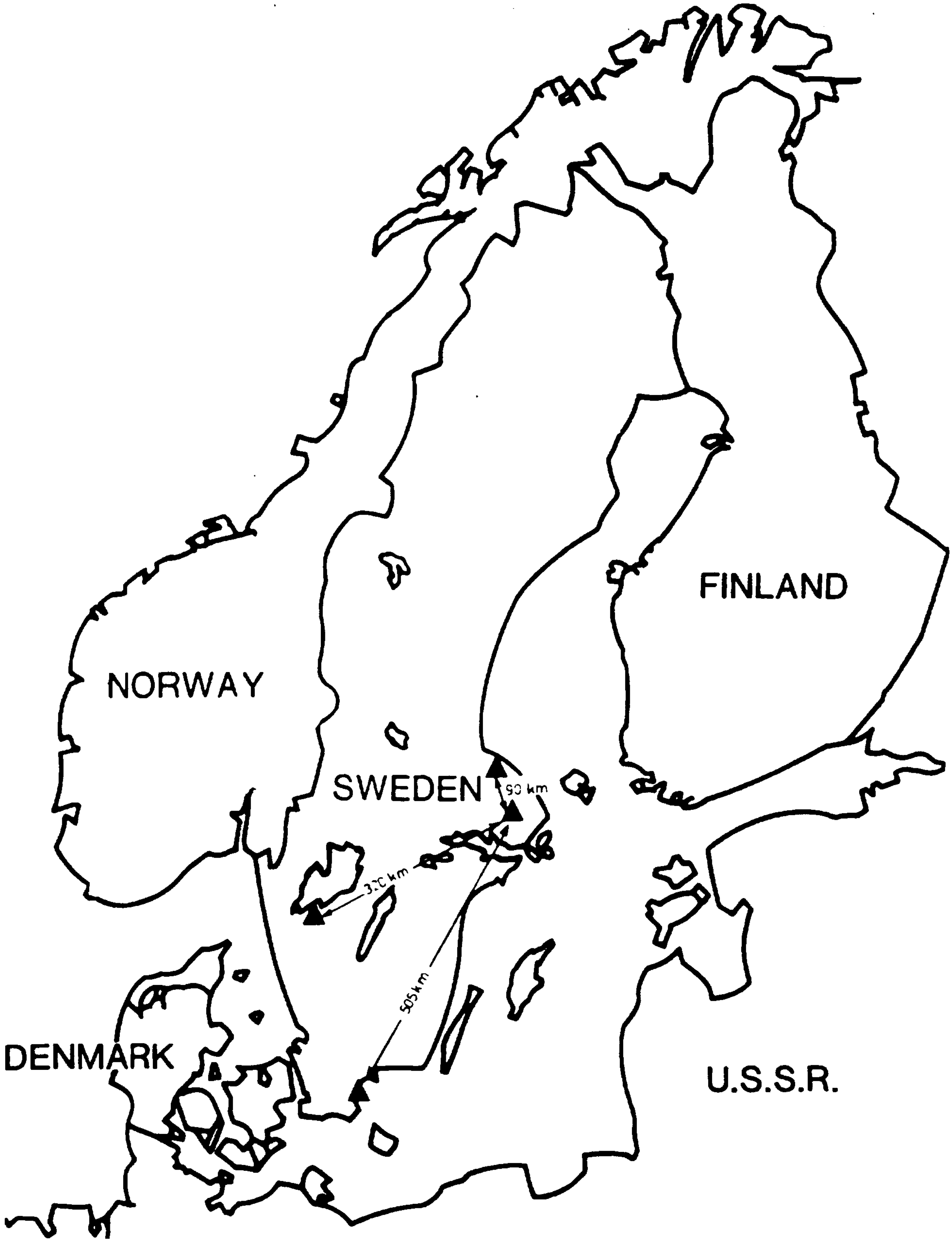

Figure 2. DF-sites in Sweden 1983

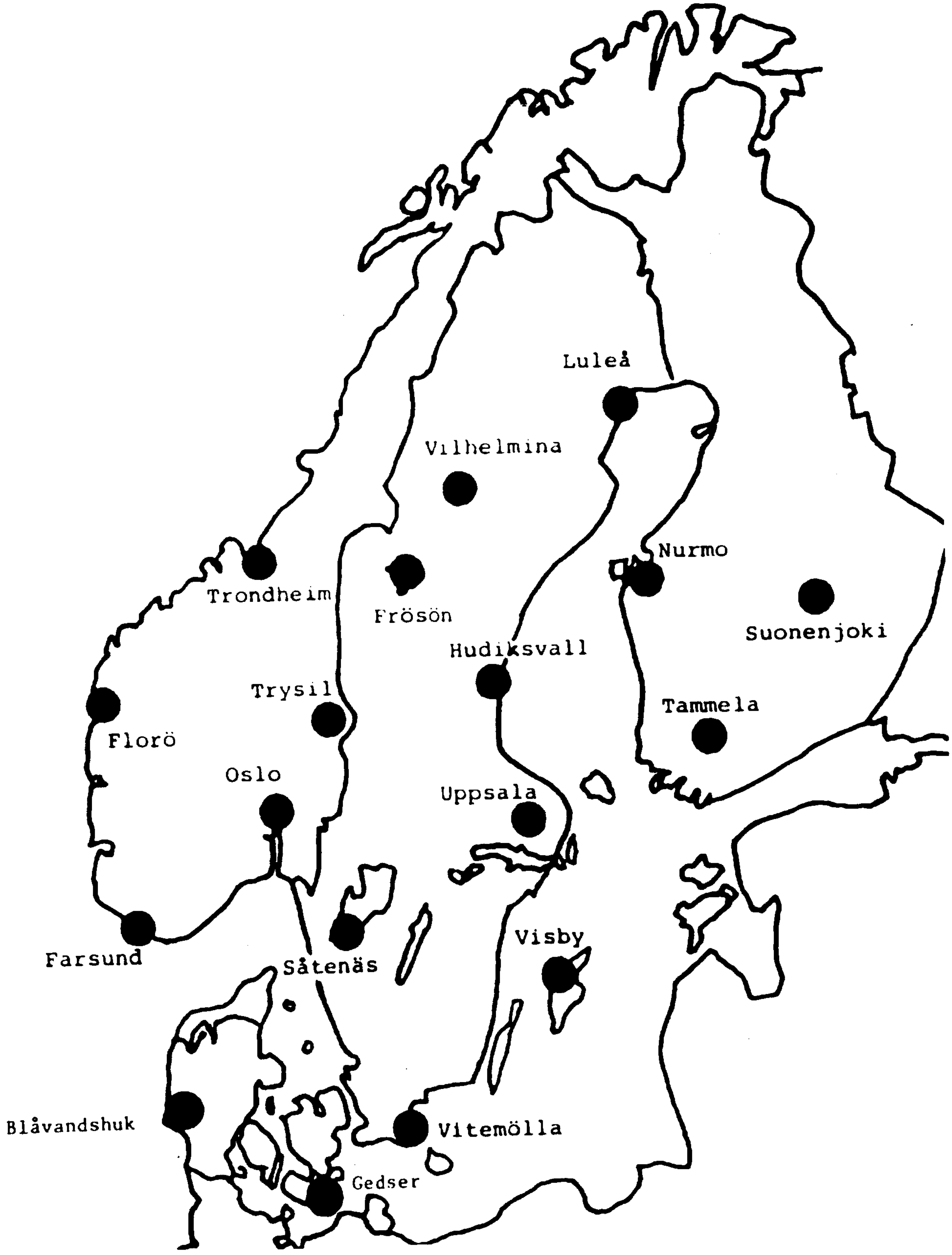

Figure 3. **DF-sites 1989 in Sweden, Norway, Finland and Denmark**

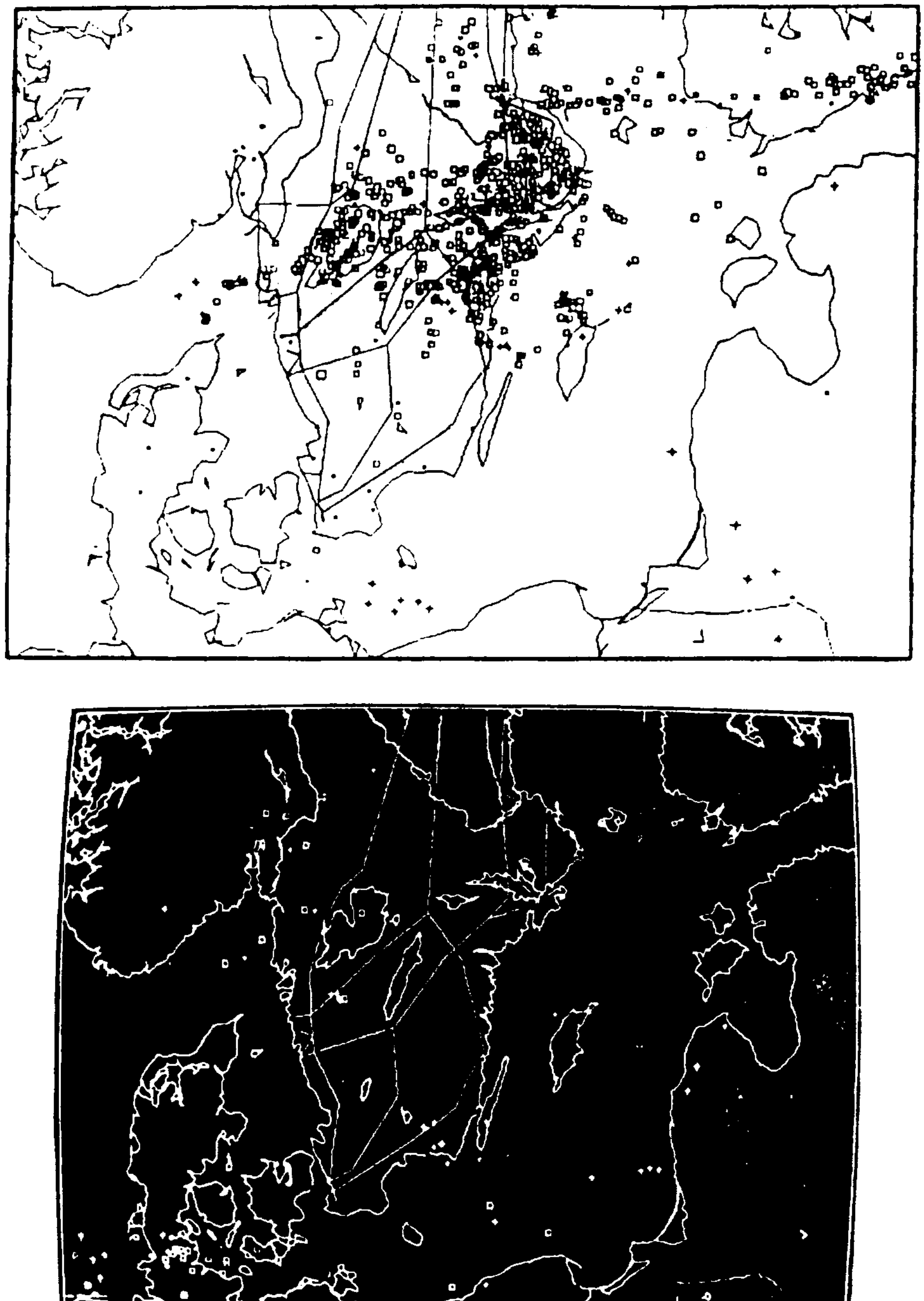

Figure 4. **Examples of real-time lightning data displays (multi-colour in reality). Please note the indicated transmission lines.**