

## Design and operation of a 50 m tall meteorological tower and data-acquisition system for realtime applications

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*This paper describes the implementation of meteorological measurement facility by installing 50 m tall towers at Kalpakkam for atmospheric dispersion studies. Though nothing novel could apparently be attributed to the idea of writing an article on the tower, the cost-effective structural design, portability–recoverability, in-house design of the signal conditioners, remote data acquisition system (RDAS) with a more generic input database covering various sensor models, user-friendly software and on-line data communication links through ethernet, e-mail, RF transceivers, etc. – all with commercially available low-cost systems – are salient novel features of the tower considered worth reporting. Traditionally occurring practical problems of maintenance, access to sensors at various levels, heavy foundation requirements for a stand-alone tower, etc. have been addressed during the design of the tower structure. On the application side, real-time tower data are obtained as input to an operational meso-scale dispersion model for nuclear emergency response management.*

Meteorological towers are the platforms providing continuous *in situ* information within the lower atmospheric layer called the atmospheric boundary layer (ABL). Most often such towers are installed for basic research studies in the ABL. Towers are also used for collecting data to assess the dispersion from tall stacks of power plants. The 120 m tall meteorological tower at Tarapur was the first meteorological tower of such height installed in our country, way back in the sixties. The tower data were extensively used to estimate the dispersion characteristics. Thereafter, towers of 60 and 30 m height have been installed at many nuclear power sites in the country in the seventies. In the eighties, a versatile 100 m tower was erected at SHAR Centre Sriharikota with the purpose of estimating wind profile and extreme wind possibilities during rocket launches. During the same period, a few towers of 10 and 30 m height were used in campaign mode for basic experimental meteorological studies like in the MONEX 1979 and the MONBLEX ten year later<sup>1,2</sup>. Short meteorological masts have been used in many campaigns in our country for micrometeorological studies<sup>3,4</sup>. The utility of long-term, persistent measurements with tall meteorological towers for basic research in atmospheric science and dispersion calculations was recognized much earlier. However, to the knowledge of the authors, there are only a few tall towers in operation presently, like those at Tarapur and Narora atomic power plants and the SHAR Centre. Except wind velocity – which is mandatory – no other measure-

ments are being made. Indira Gandhi Centre (IGCAR) at Kalpakkam planned to design, erect and commission three spatially separated 50 m towers with multi-level sensors for all the basic atmospheric parameters like wind speed and direction, turbulence intensity, temperature, relative humidity, pressure, rainfall and radiation. The data from these towers were planned for use in real time for site-specific, on-line dispersion modelling and prediction as well as for basic studies on mesoscale sea–land breeze circulation. The effort was to come out with a simple and reliable system of multilevel meteorological tower along with a data acquisition system-designed generic for various types of sensors and data-transmission techniques, which a small team of two or three scientific personnel in an institution can easily put into practice in a short time and start data analysis on-line.

### Objectives

As regards the tower, the main objective was to design a modular, portable tower at lower cost than stand-alone towers and fabricate, erect and commission the same for continuous meteorological measurements. As regards the data-logger, conventional data-acquisition systems with dedicated software and hardware have been operational so far. An ‘out-of-the-box approach’ was made to incorporate the state-of-the-art techniques in signal conditioning and data acquisition. The main objective was to not only make the system simple to operate and maintain, but

also provide an easy platform/architecture where the system capabilities can be improved/modified at a later date in case more channels have to be added or different sensors have to be incorporated or state-of-the-art data-transmission methods have to be added.

The highlight of the real-time data acquisition system (RDAS) totally designed and implemented in IGCAR, is that while an industrial PC can be used for data-logging at the tower, off-the-shelf RF communication system can be used to link and archive the data in real time at the user laboratory thus making the reliance on dedicated hardware systems, a ‘blackbox’ approach – a thing of the past. The software system installed at the tower has all the user-friendly menus for configuring the parameters and also has graphical and tabular displays of real-time data and recent data (values and trends) on the monitor.

### Structural design and erection of tower

A major component of the meteorological tower system is the tower structure (Figure 1). At Kalpakkam, a cost-effective structural design was made for a semi-portable 50 m tall tower in collaboration with Structural Engineering Research Centre, CSIR, with a life of minimum 20 years. A wind load study on the structure was carried out for understanding the design characteristics under extreme wind condition. A feature that makes the design cost-effective is that

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the tower is hinged on a platform with no large concrete foundation, whereas the guy wires are strongly anchored in four directions. The tower mast is supported on a pedestal with a hinge arrangement. The hinge assembly has been designed to transfer the compressive force to the foundation. The cost of guy foundations is cheaper than the foundation for the stand-alone tower.

The towers are lattice guyed and designed for basic wind speed of 65 m/s. The safe bearing capacity of the soil was taken into consideration, as two of the sites were sand-bearing. The tower is supported by guys at four levels, at 12, 24, 36 and 48 m from ground level with four guys at each level. The minimum breaking load for the selected 12 mm dia guy at the anticipated stress is 7.1 t, according to ISO specifications<sup>5</sup>. At the foundation, anchor provision has been made using a turnbuckle arrangement to adjust the existing level of pretension in the guys. The tension in the guy wires is maintained by observing the same in a tension meter. The guy-support foundation is based on the maximum uplift force and lateral force. Figure 2 shows the picture of the lattice tower with guy wires.

The lattice mast is square in plan of  $60 \times 60$  cm for the full height from the ground level and is built using four leg-members of Indian Standard angle sections. The mast is comprised of 6 m modules with bolts connected in double

shear at joints and staggered on the two neighbouring faces. The leg members are interconnected by rods welded as ladders on two opposite faces and by Indian Standard angle sections as lacing on the other two opposite faces. Thus, one can safely climb the tower from inside to reach the instrument levels for maintenance. Figure 3 displays the safe climb mechanism for maintenance of sensors.

The 50 m tall guyed lattice tower design was analysed using standard FEM software, by modelling the tower mast, comprising 3D beam elements, and special cable elements for the selected configuration of the tower. The turbulence intensity value was taken as 21% at 10 m level for the dynamic load patterns. The various loading environments are 3 s gust loading, patch loading for worst static effects and hourly mean wind loading with dynamic patch load patterns for fluctuating wind loading components, as suggested by Davenport and Spadling<sup>6</sup>.

For dynamic analysis of structures, representation of wind against individual frequency component is preferable since this permits relatively easy identification of the frequency component of the load that may create resonant condition of the structure. For the wind load study, measurements were made at 10, 17, 29 and 50 m levels. The turbulent spectrum of a typical data at all levels, showing variation in the energy of the wind at different frequencies is plotted in Figure 4. The

figure clearly indicates normal wind condition with lesser energy content in the high-frequency regime. It is obvious that a guyed tower can get excited in many modes<sup>7</sup>. The spectrum of measured acceleration response to detect the vibration modes of structures indicates various peak frequencies as 1.01, 1.26, 1.9, 2.0, 2.11, 2.47, 3.08 and 3.66 Hz (Figure 5).



**Figure 2.** Lattice structure, guy wires and side booms.



**Figure 1.** Snap shot of the 50 m tower.



**Figure 3.** Safe climb feature for maintenance of sensors.

The peak frequencies identified for both  $x$  and  $y$  components are about 2.03 and 2.5 Hz. It was observed that at times, respectively, there was considerable energy in the wind, specifically in cyclonic wind to excite structures having modes with frequency higher than 1 Hz. However, the range of mean wind speed is quite narrow and hence the vibration level variation with respect to measured wind speed is found to be nearly constant.

Compared to the free-standing, fixed base tower, the above design supports a totally re-locatable tower and can be implemented at a comparatively lower cost. At Kalpakkam, one of the towers is located on the coast and the other two are located perpendicular to the coast at distances of 7 and 15 km from the coast.

### Meteorological measurement sensors

The towers are instrumented at multi levels with conventional slow sensors for measuring wind parameters, temperature, relative humidity, pressure, precipitation and fast response instruments for turbulence measurement like sonic anemometer. The sensors are mounted with suitably designed sensor booms. These sensor booms are located at five heights and each boom can be retraced back into the tower for easy servicing and maintenance of sensors. The boom length was about five times the lateral dimension of the tower to minimize the wake effects. Table 1 shows the details of measurement levels and sensors.

Wind speed and direction sensors are mounted at five heights. Wind-speed sensors have an accuracy of 0.1 m/s and threshold of 0.78 m/s and are obtained with traceable certification for the calibration. The wind-speed sensors are analogue-type, generating low-level sinusoidal voltage with frequency linearly proportional to wind speed. The sensors needed signal conditioners to get an output voltage proportional to the wind speed. Individual calibration certificates for the signal conditioners are available. The wind direction sensor is of conventional conductive potentiometer-type, with an accuracy of 1% and a threshold of 1 m/s.

Relative humidity and temperature sensors are installed at three levels. It is mandatory that all the three temperature sensors match within  $\pm 0.1^\circ\text{C}$ . Locally available P-RTDs (platinum resistance temperature detectors) were used after

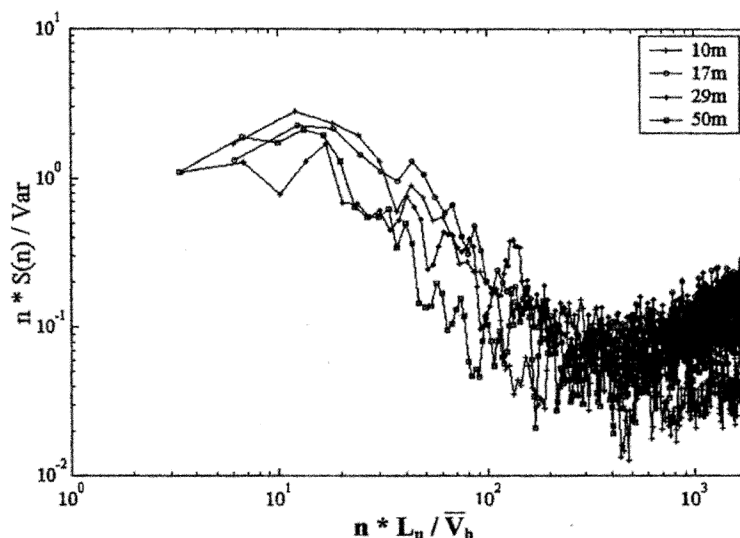


Figure 4. Turbulence spectrum of the wind measured at various levels.

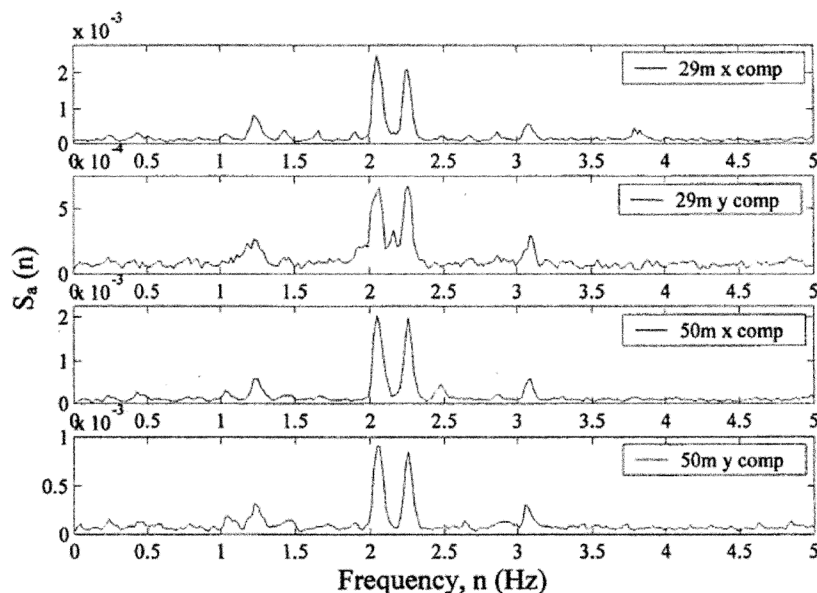


Figure 5. Vibration frequency spectrum of the tower measured using accelerometers.

Table 1. Details of instrumented levels

Parameter	Levels (m)	Sensors
Wind speed	2, 8, 16, 32, 50	NRG#40
Wind direction	2, 8, 16, 32, 50	NRG#200
Air temperature	2, 16, 50	RTD
Relative humidity	2, 16, 50	NRG
Air pressure	1.2	NRG
Solar radiation	1.2	
Turbulence parameters	10	Sonic anemometer METEK make, model USA-1
Rainfall	Surface	Dynalab tipping bucket-type rain gauge
Radioactive dose	Surface	GM detector

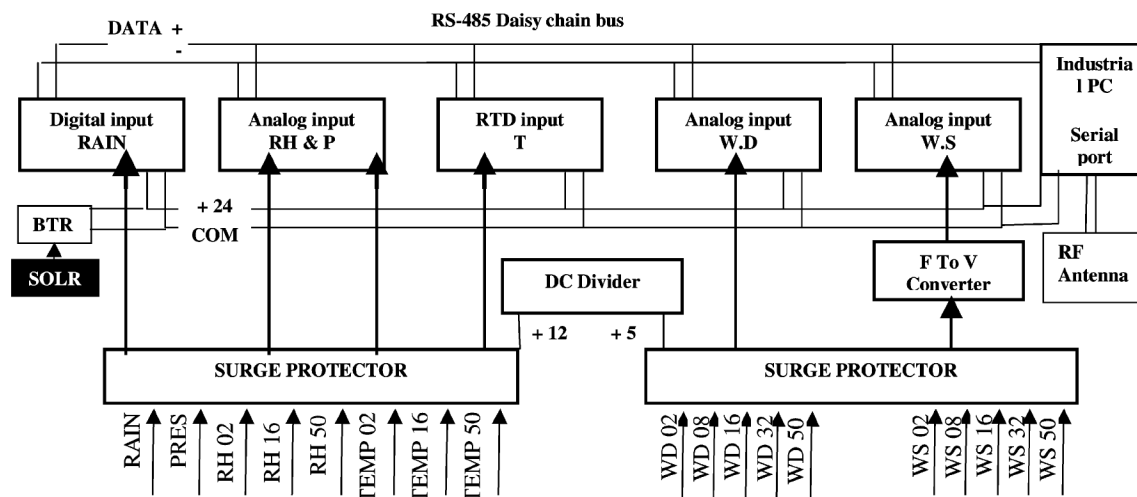


Figure 6. Schematic chart of signal-conditioner electronics and wiring.

ensuring that a set of three chosen from the lot showed the required accuracy under a given atmosphere. As the lead length for temperature sensors varied from 2 to 50 m, it was decided to use the four lead configuration to connect the RTDs.

The pressure sensor used is a micro-machined integrated circuit absolute pressure sensor with a range 115–1150 mb. Tipping bucket-type of precipitation sensor has been installed on a small pedestal, at a distance from the tower. It has a sensitivity of one pulse for 0.5 mm of rain.

As already mentioned, some of the sensors like those for measuring wind speed need signal conditioners, while sensors for monitoring direction, pressure, solar radiation and relative humidity need excitation voltage sources.

### Electronics and instrumentation

The most important components of the meteorological tower that requires frequent maintenance and upgradation are the sensors, mounting mechanism, cable connectivity, electronics and data-logging system. After a few years of operating experience, a methodology was evolved in designing these components in such a way as to minimize the maintenance hassle. The method is described in detail.

The signal cables from the sensors are brought to the base of tower where they terminate in surge suppressor network. These surge suppressor boards have surge voltage protectors in the form of transient

voltage suppressor diodes and lightning protectors like gas-discharge tubes of suitable ratings. It is a normal practice to terminate each incoming wire in a surge suppressor termination. One such board has the provision to connect 20 incoming cables; the signal is then connected to the front-end modules or signal conditioners as the case may be. Figure 6 shows the sketch of the signal-conditioner electronics and wiring. The front end of the acquisition system is based on a distributed network wired in an RS-485 daisy chain and connected to one of the COM ports of a computer through an RS485 to 232 converter. Distributed network modules with analogue voltage, RTD or digital pulse as input are used in a daisy-chain formation. The advantage of employing the distributed network modules in this configuration is that after all the wiring is completed in the field, the COM port can be scanned for the modules through the software utility. It is possible to individually see the voltage values at each of the channel inputs. Since the modules are connected in a daisy chain, each of the modules needs to have a unique address that is pre-specified. These modules take 10–30 V DC (unregulated) as power supply and have operating temperature range of up to 70°C. EIA RS-485 is the most widely used bi-directional, balanced transmission line standard in the industry. As is known, RS-485 standard uses a single pair of wire to send and receive data. It is specially developed for industrial multi-drop systems and can have maximum line length per segment of 1200 m.

Since the nodes are connected in parallel, they can be disconnected from the host without affecting the performance of the remaining nodes. The biggest advantage of using such a configuration is that the main data-acquisition system, i.e. the industrial PC can be located anywhere. The PC can be housed in a weather-proof shelter box fixed on the tower, so that no separate room or cabin is required. It can also be kept in a laboratory away as far as 1 km from the tower, the connecting cable being a two core cable from the RS-485 daisy chain to the laboratory.

The universal network controller concept was selected for the hardware part of the DAS that links the data to the software. It is a system that has an application-ready platform and supports several standard networking interfaces, such as ethernet, wireless ethernet, RS-232, RS-485 and on-board I/O interfaces. It has an open architecture and is extremely reliable in the field as it has a fan-less, cable-less architecture. The system has a strong mechanical design, and has excellent anti-shock and anti-vibration properties and is designed to operate on any one of the dual DC power sources (+24 V, 15 W) with automatic switching built-in. This feature was made use of in designing the power supply so that the mains derived DC and a solar power-charged battery constituted the two DC sources. The battery charging is controlled through a solar-charge controller of suitable current rating. The system hardware is shown in Figure 7. The system was found to be extremely rugged



and robust, and suitable for use in harsh and critical environments, such as the one we have at the Kalpakkam tower location, a coastal site.

### Data acquisition system and software

Data acquisition, archival and on-line analysis routine has been completely designed using a generic data-logging software. Most of the readymade, field-installed DAS does not have the real-time graphical output facility. The present DAS has a number of data-display screens that can display the real-time data on-line in different forms. At the same time, data can be transferred to a central server located as far away as 16 km through RF transmission network. To ensure that all the modules are configured properly and inputs are read correctly before the sensors are connected, the DAS can be simulated with test signals and the output can be checked.

The application software has been designed around DASYLab 8.0. The data-acquisition software can reside in any off-the-shelf, commercially available computer and thus the complete system would not be a dedicated unit needing specialized expertise in handling the same. DASYLab has all the provisions for data acquisition, analysis and archival. It also has a number of data-presentation schemes and can support a number of third-party modules.

The menus are configured using various functional modules available in DASYLab and each individual application can be saved as a worksheet. The worksheets have extensions .DSB. In an actual application case there can be a number of worksheets, such as those for setting the system parameters, engineering conversions, data-acquisition modes and selecting different data-display modes. The .DSQ is a sequencer file which links all the .DSB worksheets and provides the complete software solution for the given application. The actual program is thus a combination of the .DSQ and .DSB files. For automatic start-up in the case of power interruption, the .DSQ file needs to be put in a batch file along with its path, and this batch file needs to be placed in the WINDOWS-START UP folder.

Through averaging time selection menu, averaging time can be selected from a list of choices and set to any one of the

seven averaging times offered. The options are 2, 5, 10, 15, 20 and 30 min. In engineering-conversion menu, the choice of sensors for measurement of various meteorological parameters is made and the

installed sensor in the mast or tower is selected here so that the correct conversion factors are used for a proper estimation of the parameters from the given voltage or resistance value. Figure 8



Figure 7. Distributed network modules and signal-conditioners at the base of the tower.

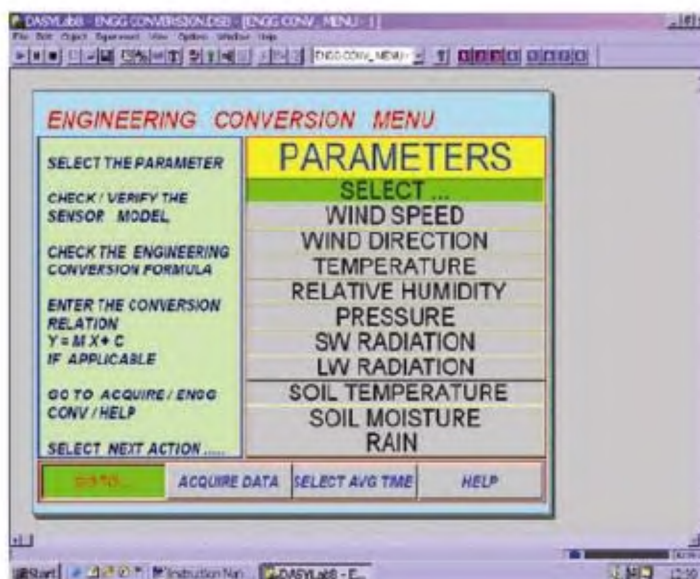


Figure 8. Parameter selection screen in engineering-conversion menu of the software.

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shows the parameter selection screen, where the required parameter is chosen first before the installed model of a particular sensor is selected in the corresponding choice screen. For example, Figure 9 shows the choice available in rain sensor models.

The data acquisition menu enables one to acquire the data and display them in terms of lists, tables, graphs and also show the various data files being archived in real time.

There are screens to show: current data in digital display and other suitable formats; current and recent averaged data in table form; recent data/trends in graphical form; recent data in the form of list, and hourly averaged data in list form.

The salient feature of the software developed for this system is that all the above features and various screens can be viewed in real time and on-line without interrupting the data acquisition during the actual logging stage in the field. Further, there is information available as to the sensors selected, their conversion factors and also details regarding the hardware modules along with their addresses and connection details. Careful scanning of information would ensure that the installed sensors are indeed selected and that the data-acquisition system configuration is correct. The software also includes some diagnostic features. In addition, the current data file and information regarding data transferred are also shown along with the real time and the selected averaging time.

### Data structure

There are a number of data files archived during data acquisition. The data files are written at the end of the selected averaging time (presently set as 10 min) and also at the end of an hour.

These data files correspond to averaging-time data file and hourly averaged data file. The files are in ASCII format.

The sampling frequency and averaging time of data acquisition are user-selectable. Presently, the sampling frequency is 0.1 Hz and averaging period is in two modes as mentioned earlier (10 min and 1 h). The file name is XXXYYMMDD.ASC, where XXX is the station identification code and YYMMDD represents a number made of two digits each for year, month and day. ASC indicates that the data file is in ASCII format. This file

at the end of the day would have 144 entries corresponding to one dataset for every 10 min.

### On-line data links

The RDAS has the capability for many modes of real-time data communication with remote central stations. The data can be obtained through ethernet, e-mail or through an RF data link using appropriate RF modems and high-gain antennas. The default COM port used is COM1 for connecting to data-acquisition modules. COM2 is the default COM port used for enabling data links.

A provision to transmit the data on request using RF transceivers has been built into the system software. A15 dBi omni-directional RF antenna has been installed on the tower. The RF Tx/Rx modules can be in point-to-point configuration or Master to Mutipoint configuration. Due care has to be taken to ensure that the line-of-sight criterion is met when long-distance data transmission and reception is involved. As is known, data communication through RF is subject to the terrain topology, antenna-type and gain, height of the antenna installation and partly on the weather conditions. The last is not critical at the ISM band of frequency 2.4 GHz used here. Upon an in-

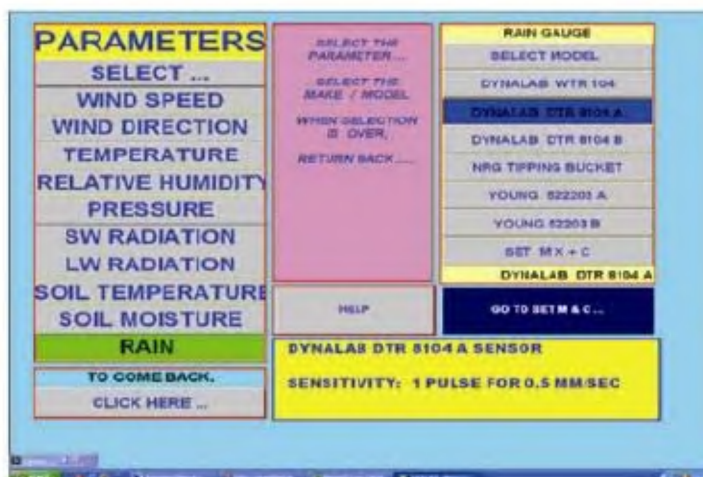


Figure 9. Choice of rain sensor models from the look-up menu.

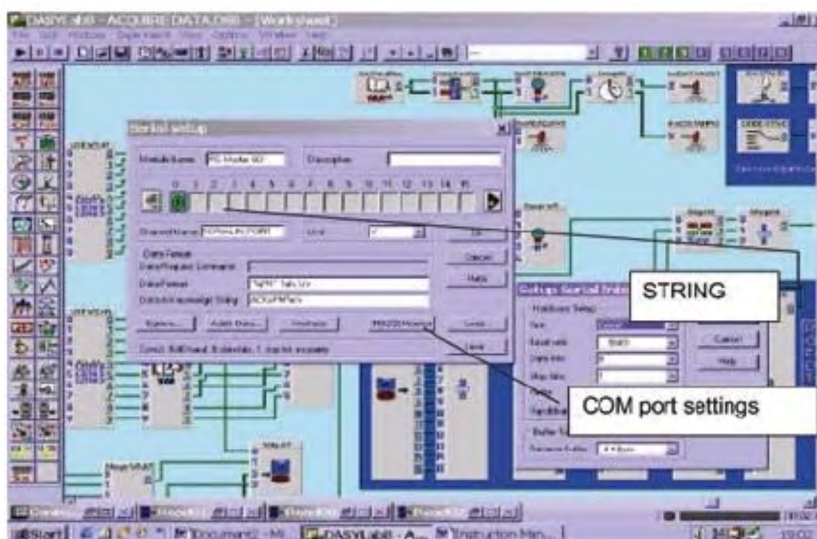


Figure 10. Transmitter configuration screen.



coming request defined in the 'STRING' variable during the installation, the DAS at a particular station responds by sending the data file. The string defined here can be a password or user-specific code when the system is to be used in strategic locations (Figure 10). On receipt of the code, the DAS will send the dataset for transmission. The RF modules are connected to the DAS at the tower and a PC at the receiving end by direct RS 232 cable.

In the present installation, the 10 min averaged tower data are received by a server located about 8 km away from the tower and through a web portal the same is displayed to clients in the local LAN of IGCAR. A typical display of data is shown in Figure 11.

### Tower data input in real time into a dispersion model

An on-line radiological emergency response system comprising a nested-scale weather model and a particle dispersion model is implemented in real-time live mode as part of the Decision Support System. The system provides forecast of the plume assuming a hypothetical unit release rate condition. The global assimilation and forecast data are taken from NCMRWF, New Delhi on a daily basis. Local data from the 50 m towers are used to initialize the weather forecast model MM5, in addition to the global data<sup>8</sup> through a module LITTLET in the MM5. A comparative study of the model performance with and without local data is initiated.

However, for on-site assessment in real time over a small local region of 10 km radius, data from the towers are directly used by an atmospheric dispersion code system to give real-time radioactive dose predictions due to inadvertent releases from a nuclear reactor. This numerical system consists of a diagnostic mass-consistent wind-field generation module and a Monte Carlo Lagrangian Particle Model for dispersion<sup>9</sup>.

The wind-field module takes the tower data from each location in real time with an interval of 10 min (averaged) and generates the heterogeneous wind field over a radius of 10 km around the site. The dispersion model uses the measured temperature gradient and the wind speed for estimating the stability condition for dispersion simulation. The site characteristic features like coastal fumigation,

landuse, etc. are incorporated so that the estimated radioactive plume doses are more realistic than those obtained using a simple Gaussian Plume Model.

Figure 12 shows a simulated plume of airborne radioactivity and the area of im-

pact for a hypothetical release of <sup>131</sup>I iodine isotope. The computations are automatically carried out continuously and integrated with a web-based Decision Support System. The tower data and results of these computations are avail-



Figure 11. Real-time data through a portal in the LAN.

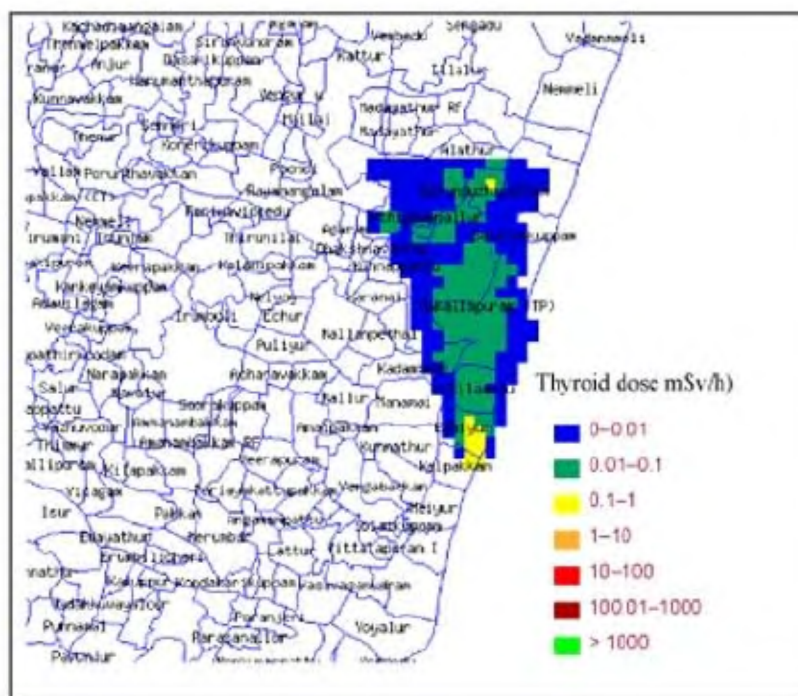


Figure 12. Real-time radioactive plume dispersion for a hypothetical accidental release. Site-specific meteorological data from the 50 m towers are used as on-line input to the dispersion model.

able in the campus network for use by emergency managers.

## Summary and conclusion

A 50 m tall guyed mast was designed for maximum wind speed of 65 m/s and was erected at three locations. The tower design was subjected to wind-load studies. A rugged, user-friendly data-acquisition system was designed around an industrial embedded computer platform with RS 485-based embedded modules powered by solar panels located near the tower base and works on solar energy. The operating parameters and data from all the sensors on the tower are displayed in various screens in real time. The complete system implementation is based on indigenous know-how and does not depend upon any dedicated commercially available data-acquisition systems. The hardware design is based on off-the-shelf signal handling modules and any changes in the number of channels or configuration can be done easily by the user. Sensors of various makes are included in the database so that the user can choose the

type of sensor without bothering about configuring the DAS with the respective engineering conversion units. The main objective is not only to come out with a tower system design simple to install, operate and maintain, but also provide an easy platform/architecture where the system capabilities can be improved/modified at a later date. The system has been in continuous use in the field and has been providing input data to the real-time dispersion model of a Decision Support System for radiological emergency.

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