Implementation of a novel SCADA architecture for a 210 MW Thermal Power Plant

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***Abstract*—Control and Instrumentation Group at the Centre for Development of Advanced Computing (CDAC), Thiruvananthapuram, has deployed an integrated control and monitoring system at a 210 MW thermal power plant in India. This system has all the features of an advanced Supervisory Control and Data Acquisition System (SCADA) and in addition has support for web-based SCADA. This paper outlines and discusses the various hardware and software components used in this SCADA system. How these basic components are combined in realizing various subsystems of this SCADA like the Prediction based Superheater and Reheater Steam Temperature Control, Genetic Algorithm based Pulverized Coal Flow Soft Sensor and Wireless Monitoring of Cooling Water Pump House are also detailed.Various results obtained with this SCADA system in place are pondered upon. The main objective of this paper is to bring out the salient features of this SCADA system against the backdrop of a critical and dynamic environment as in a 210 MW coal-fired thermal power plant which expects maximum efficiency and minimum downtime from a SCADA system overseeing it.**

***Index Terms*—SCADA; superheater; controller; thermal power plant; iCON; iROSE; iWase; iWiSe; iRESS; CDAC.**

I. Introduction

India is a country which has a very big footprint on the world map in terms of its power generation and consumption profile. Statistics show that [1], about 65% of the electricity consumed in India is generated by thermal power plants, 22% by hydroelectric power plants, 3% by nuclear power plants and rest 10% from other alternate sources like solar, wind, biomass etc. Hence, it is very evident that thermal power plants especially coal-fired thermal power plants have a very big role to play in the Indian power sector. That also means that these plants should be operated with utmost discipline, employing state of the art integrated control, monitoring and communication systems to cater to the various subsystems of the plant, thus ensuring maximum operating efficiency and minimum downtime.

In this context a novel SCADA architecture developed at CDAC, Thiruvananthapuram, is presented. This architecture comprises of several key elements (or components), which are used in the automation system deployed at the 210 MW thermal power plant. The main elements developed are :

1) iCON : An industrial rack based modular controller platform using CDAC proprietary Distributed Automation Control System (DACS) protocol.
2) iWise : An industrial wireless sensor node supporting IEEE 802.15.4 protocol.
3) iWase : An industrial wireless base station supporting IEEE 802.15.4 and DACS protocol.
4) iROSE : A scalable, flexible and extensible SCADA software supporting native DACS protocol for communicating with hardware and having optional Web SCADA feature.
5) iRESS : An industrial real-time expert system shell to develop Knowledge Based System (KBS).

The paper discusses briefly about each of these basic components and then move on to describe how these basic elements are combined to realize the following functions of the SCADA system in the thermal power plant :

1) Kalman Filter based steam temperature prediction control in Superheater.
2) Evolutionary Computation based soft sensor for pulverized coal flow measurement.
3) Expert System for operator guidance in Coal Mill.

978-1-4799-5461-2/14/$31.00 ©2014 IEEE

4) Monitoring of motor winding temperature for cooling water pumps.

II. Basic Components

A. Industrial Controller (iCON)

iCON is a robust, modular, scalable, rack based industrial controller envisaged for process industries. It embeds Linux operating system with real-time functionality, to augment the system for real-time applications. This controller platform has two onboard CPU modules each based on 200 MHz Freescale Coldfire processor for executing control algorithms and handles HMI communication using CDAC proprietary DACS protocol.The CPU modules in an iCON are in hot standby [2] [3], with the standby CPU module always ready to take over control from the active CPU module, the instant failure occurs in the active CPU module. CPU module in an iCON scans and updates its input and / or output to a set of Input / Output (I / O) modules. Up to 38 I / O modules can be handled by one CPU module, which is configurable remotely via HMI. The various types of I / O modules available in the iCON controller platform are :

1) 16 channel 230V AC / DC Digital Input Module with optical isolation
2) 16 channel 24 / 48V Configurable Digital I / O Module with optical isolation
3) 8 channel 4 - 20 mA / 1 - 5V Analog Input Module with optical isolation
4) 8 channel 4 - 20 mA / 1 - 5V Analog Input Module with relay isolation
5) 8 channel 4 - 20 mA Analog Output Module with optical isolation

All these I / O modules along with the CPU modules has hot-swap capability, allowing seamless extraction and insertion of these modules while the controller is running, without affecting the operation of remaining modules in the rack. Apart from CPU redundancy, iCON also features power supply redundancy, network redundancy and I / O link redundancy [2] [3].

B. Industrial Wireless Base Station (iWase)

iWase is a standalone panel mountable device which can acquire and process sensor readings from nodes in the Wireless Sensor Network (WSN) and make it available to the external world (user) via wireless or wired interface. The Wireless Base Station unit acts as a gateway between the WSN and the external world. The iWase [4], built around a powerful ARM9 controller, acquires radio packets from sensor nodes using an IEEE 802.15.4 radio and relays it to a central monitoring station via Ethernet or GSM / GPRS network using DACS protocol. The iWase is also equipped with an ingress protection of IP65 and facilitates operation in the industrial temperature range of -40 to 85°C.

C. Industrial Wireless Sensor (iWiSe)

iWiSe is an ultra low power wireless sensor node capable of acquiring and processing signals from any industrial sensor and transmits the information wirelessly to a base station unit for monitoring and control. The iWiSe mote, built around an ultra low power 16-bit microcontroller, collects field information in the form of analog and digital signals and relays it to a base station using the on-board IEEE 802.15.4 2.4GHz transceiver. The iWiSe is equipped with an ingress protection of IP65 and facilitates operation in the industrial temperature range of -40 to 85°C.

D. Industrial Range Open SCADA Software (iROSE)

iROSE is the Human Machine Interface (HMI) software used in this SCADA system. It is a web-based software, so that it can be accessed from any client computer, which has a Web Browser that supports Flash Player. A standalone version of the HMI is also available in this system. The software is highly scalable, layered and has a distributed architecture so that it can be effectively used in small plants as well as in enterprise wide networks. It is an open and standards based SCADA software which provides easier configuration and installation capabilities.

iROSE can acquire data not only from hardware developed by CDAC like iCON and iWase, but also from controllers that support legacy open protocols such as Modbus TCP [5], IEC 60870-5-104 and DNP 3.0 TCP [6]. iROSE makes use of the OPC DA v2 standard [7] for system interconnectivity and thus provides a standard based infrastructure for the exchange of process control data. iROSE configured in the thermal power plant mainly consists of a CDAC proprietary protocol known as DACS, which acquires data from controller like iCON and from the wireless base station iWase. Fig. 1 depicts the various components in the iROSE SCADA software.

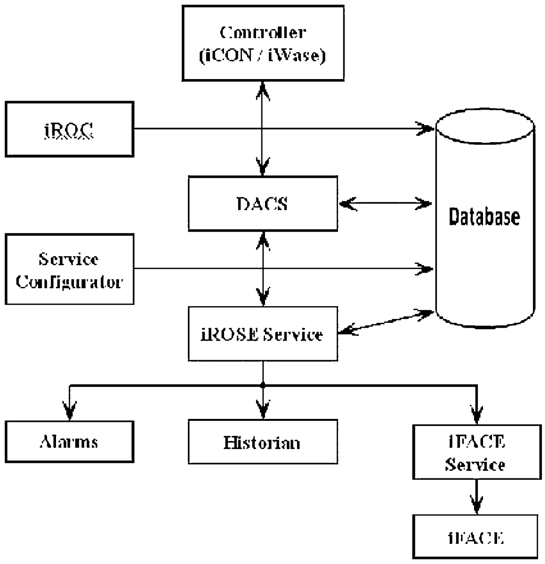

Fig. 1. Block Diagram of iROSE

iROSE is primarily composed of 3 software packages :

1) iFACE: iFACE is the user friendly web and standalone HMI component of iROSE. iFACE is an easy to use, full featured HMI that enables full control and visualization capabilities over the intranet. With the help of HMI, a user can configure the display for Trend, Bar Graph, Value display etc. Other features in this package are Faceplates for PID Controller, process dialog for supervision and control, Tag Browser to display online tag values in tabular format, alarm management, real-time Trend etc.

2) iDLog: iDLog (industrial Data Logger) or the Historian is the historic logger which logs online data into a database at a predefined interval as configured. There are different types of logging support like scheduled, periodic and log on change.

3) iROC: iROC is the remote configurator package in iROSE for configuring iCON and iWase modules. Control strategy is configured by means of Loop Configurator and by means of simulation package in iROC. All the control strategies can be tested before downloading it to the controllers, where Functional Block Diagrams based on IEC 61131 standard is used.

E. Industrial Real-time Expert System Shell (iRESS)

Knowledge Based System (KBS) [8] has an important role to play, particularly in fault diagnosis of process plants, which involve lot of challenges starting from commonly occurring malfunctions to rarely occurring emergency situations. The KBS approach is promising for this domain as it captures efficient problem-solving of experts, guides the human operator in rapid fault detection, explains the line of reasoning to the human operator, and supports modification and refinement of the process knowledge as experience is gained. iRESS is a software development environment containing the basic components of Expert Systems.

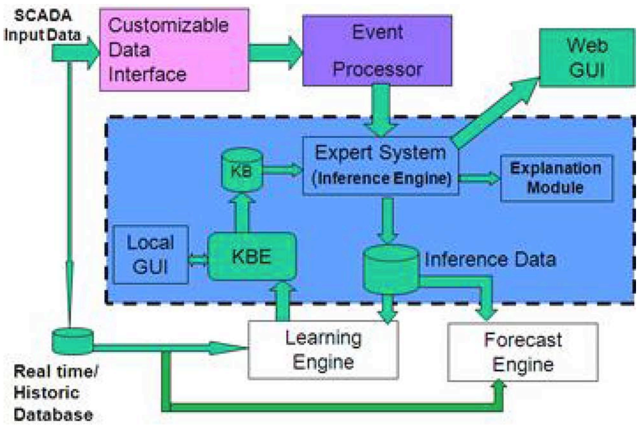

Fig. 2. Block Diagram of iRESS

As depicted in Fig. 2, this shell toolkit [9] can be used to develop an intelligent system for diagnosis and root cause analysis along with operator guidance in process plants. For a particular application development using the Expert System Shell, the Knowledge Base (KB) has to be developed with rules and attributes relevant to the target system. The object based iRESS is an integrated software tool which can be used by system developers and domain experts to develop KBS. This tool allows creation of KB by encoding an expert's knowledge as a set of rules and frames and does inference using built-in backward or forward chaining Inference Engine. The tool is designed to interface with external SCADA systems via plug-in modules which support standards like Object Linking and Embedding for Process Control (OPC). It also supports explanation facilities. Applications developed with iRESS are used in problem-solving and decision-making The Learning Engine learns new knowledge from process data and updates KB, thus improving the efficiency of the system in root cause analysis. The Forecast Engine does failure prediction which can help in preventive maintenance of the plant. In Online mode of iRESS, Event Processor module inputs the highest priority alarm to Inference Engine. Inference Engine uses KB and online data in working memory for diagnosis. The final result of the Alarm analysis is displayed in a separate window with supporting images if any, stored in the database earlier by the user.

III. System Architecture

Fig. 3 depicts an overview of the architecture of the SCADA system for the automation of thermal Power Plant. As depicted in Fig. 3, three numbers of iCON are used, one each for Superheater Steam Temperature control, Reheater Steam Temperature control and Pulverized Coal Flow Soft Sensor. iWase and iWiSe modules are used for wireless monitoring of motor bearing and winding temperatures in the Cooling Water Pump House. All these data are concentrated at the SCADA Server station which runs the SCADA software iROSE. iROSE distributes the relevant data to all the Operator Workstations which are 4 in number, catering to general operator interface, Genetic Algorithm based Pulverized Coal Flow Soft Sensor interface, iRESS based Expert System interace for operator guidance and interface for Cooling Water Pump House monitoring. The developed hardware components and the SCADA Server and workstations are networked using two numbers of layer-2 managed ethernet switches.

As shown in Fig. 3, multiple iCON's connected to the SCADA Server form a scalable and redundant, distributed SCADA architecture. Fig. 3 also depicts the CPU and Network Redundancy scheme used in iCON, with the network highlighted in blue going to one CPU module whereas the one highlighted in red is terminated at the redundant CPU module of that iCON.

A. Superheater Steam Temperature Control

Superheater in the thermal power plant is organized in three sections :

1) Low temperature Superheater (LTSH)
2) Platen Superheater (PTSH)
3) Final Superheater (FSH)

Saturated steam from the boiler burner first passes through LTSH, then to the PTSH and FSH. In order to control the main steam temperature at the desired value, cold water spray is applied at the De-Superheater (DSH) at the inlet of the PSH.

The main steam temperature at the left side is measured with three thermocouples and the mid value is selected. Similarly, the DSH outlet temperature is measured with three thermocouples and its mid value is selected. The main steam

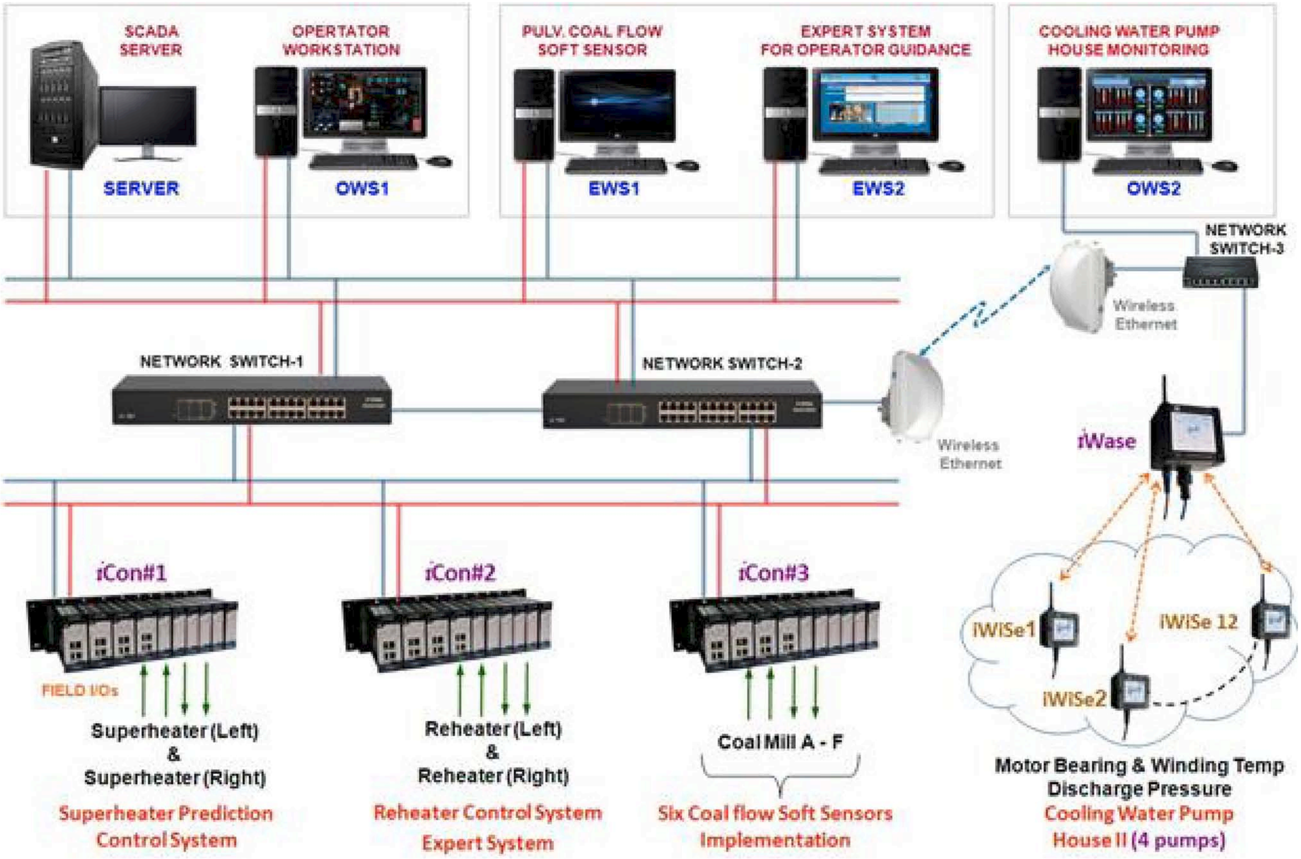

Fig. 3. System Architecture

temperature control system for the left side consists of one PID Controller for steam temperature control and another PI Controller for spray control connected in cascade mode. The Controller output actuates the motor operated Main Spray Control and a by-pass Spray Control Valve through a selector mechanism. The same arrangement is provided for control of steam temperature at the right side as well.

The architecture of the new control system as shown in Fig. 4 consists of four important building blocks :

1) Conventional steam temperature control system
2) Superheater model
3) Kalman FIlter state estimator and predictor
4) Online model adaptation

The conventional steam temperature control system employing PID controller is a proven control system and has been accepted by the thermal power plants since many years. Due to this reason, this conventional steam temperature control system is chosen as the basic building block for the new control system. Other building blocks like superheater model, Kalman Filter state estimator and predictor [10] [11] and onlie model adaptation are used to enhance and optimize the performance of the conventional control system for obtaining minimum possible steam temperature deviation from the set-point in closed loop control. These blocks basically perform modelling, state estimation, filtering, prediction and adaptive parameter estimation functions as envisaged in the new system

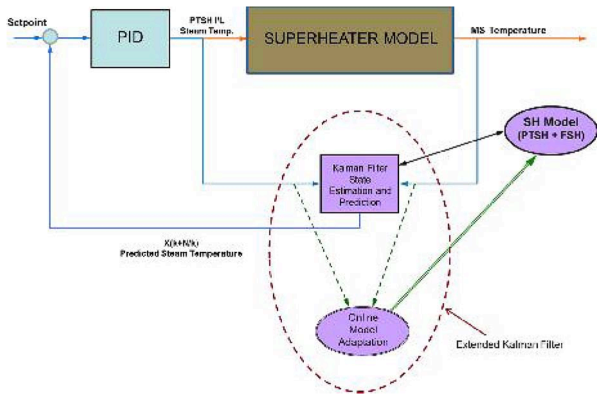

Fig. 4. Steam Temperature Prediction Control Scheme

architecture [12].

The steam temperature control system implemented using Extended Kalman Filter (EKF) captures the plant behaviour during various operating regions and is able to provide a clear estimate of the steam temperature deviation that can happen in the future. This feature enables both the automatic and manual modes of attemperator spray control, as it is based on a more realistic estimate of the future variations of steam temperature. The real-time predictive steam temperature response that is obtained from the EKF implementation at the power plant is given in Fig. 5. Here this response is compared against the measured steam temperature in the conventional approach.

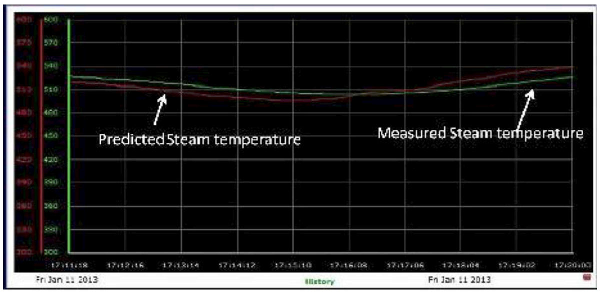

Fig. 5. Trend in iROSE comparing EKF and non-EKF responses

B. Soft sensor for pulverised coal flow measurement

At present no proper instrumentation is available for the measurement of pulverised fuel flow. A more accurate estimate of the same will be much useful for the plant operator to decide the air-fuel ratios and thereby controlling the plant in a more economical way [13].

A Coal Mill model based pulverized coal flow estimation system is implemented in this project. The model of the Coal Mill is developed by using the first principle mass and energy balance equations for the purpose of providing good estimates of the internal dynamics of Coal Mill. Genetic Algorithm [14] is used to identify the 15 unknown Coal Mill model parameters. The optimization of the model using Genetic Algorithm is done periodically, once in every 4 hours, so that the model follows the mill characteristics under varying mill conditions. The model output of pulverized coal measurement is compared with the available raw coal measurement and the accuracy of the soft sensor for pulverised coal flow is less than 0.5%. The model construction is focused for the entire coal pulveriser system, which consists of 6 Coal Mills. The scheme of the pulverised coal flow estimation system is shown in Fig. 6.

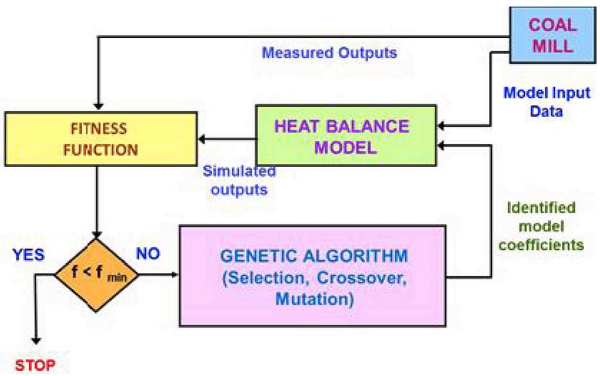

Fig. 6. Scheme of Pulverized Coal Flow Estimation

C. Expert system for operator Guidance in Coal Mill

The iRESS software package is installed in the thermal power station for root cause analysis of alarms and operator guidance. The plant data is received in iRESS by OPC interface via iROSE SCADA software. In this implementation of iRESS, the KBS has been built with rules and frames for Mill A. KBS is built for diagnosis of Coal Mill system fault alarms in the plant. 27 signals (Tags) have been configured (20 Digital Input (DI) and 7 Analog Input (AI) signals) in iRESS and the same is also logged in Historian database (iDLog). The knowledge is collected from a domain expert and it is formulated in the form of flowcharts. One sample flowchart is shown in Fig. 7. The flow chart contains the critical alarm with all its sub-causes and root cause.

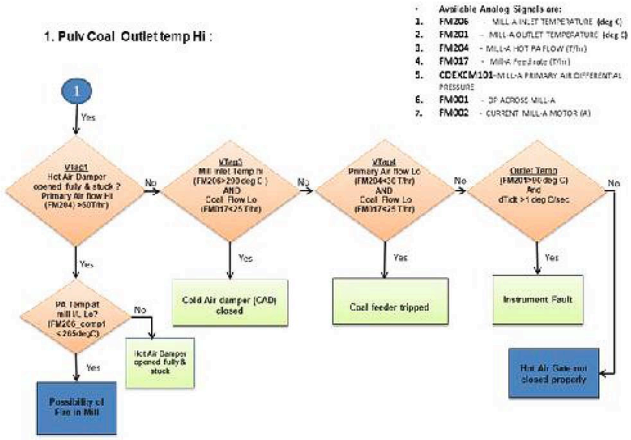

Fig. 7. iRESS Flowchart - Pulverized Coal Outlet Temperature High

In the output screen of alarm diagnosis the alarm name with time of occurrence, root cause of the alarm, operator guidance, root cause image etc will be displayed. The KBS can be extended for other mills of the plant also. By using the iRESS based fault diagnosis system, the plant downtime is reduced since alarms / faults are diagnosed in real-time and better operator guidance accelerates restoration of normal conditions. The Learning Engine enhances the Expert System by forming new rules dynamically. The new rules formed are validated by the domain expert and then the rules are updated to the KBS.

D. Wireless Monitoring of Cooling Water Pumps

Even though steam generation and temperature management is the fundamental requirement for generation of power in thermal power plant, steam condensation is equally important for efficient and safe working of the plant. The condenser condenses the steam from the exhaust of the turbine into liquid to allow it to be pumped. If the condenser can be made cooler, the pressure of the exhaust steam is reduced and efficiency of the cycle increases. For best efficiency, the temperature in the condenser must be kept as low as practical in order to achieve the lowest possible pressure in the condensing steam [15].

Thermal power plants generally use either circulating cooling water from a cooling tower to reject waste heat to the atmosphere, or once-through water from a river, lake or ocean [15]. This thermal power plant being located very near to the sea uses sea water for cooling purpose in the condenser. Two Cooling Water Pump Houses located near to the sea, pump sea water towards the plant. Uninterrupted functioning of these pumps are critical for the cooling operations in the plant, which necessitates continuous status monitoring of these pumps. It is difficult to lay cables for conveying the status signals to the plant on account of the pump houses being located far from it. Moreover the harsh plant conditions makes maintenance difficult and expensive. Presently, an operator takes periodic recording of the pump parameters and informs the operator at the plant control room who takes necessary corrective action.

Since wired form of communication is not a viable solution in the concerned plant, a wireless system has been implemented for monitoring the status of the Cooling Water Pumps [16]. Unlike many variants commercially available in the market, both iWiSe and iWase modules are industrial grade modules designed to operate in harsh environmental conditions with an ingress protection of IP65. Hence, a WSN monitoring system based on iWiSe and iWase is aptly suited for the purpose. These modules are also tested and certified based on IEC 61850 standard.

The system consists of 12 iWiSe nodes deployed at the Cooling Water Pump House which collectively monitor parameters like winding temperature, bearing temperature and discharge pressure of the 4 Cooling Water Pumps on one unit of the plant. The sensed information is then wirelessly transmitted over to iWase, which forwards it to the iROSE server via a Wireless Ethernet Bridge. The field information is then displayed in a Cooling Water Pump mimic diagram in iFACE.

IV. Conclusion

A bird's-eye view of the SCADA system developed by CDAC, Thiruvananthapuram, and deployed at a 210 MW thermal power plant is presented in this paper and the various components that make up this SCADA are briefed. Based on the results obtained from their use in different sub-systems of this power plant, it is evident that the system brings in a lot of value addition and convenience for the plant operators. Various types of redundancy mechanisms and hot-swapping features in iCON justify its use in critical sub-systems of the plant like superheater steam temperature control and pulverised coal flow measurement in Coal Mill. Like wise wireless monitoring of Cooling Water Pump House is very useful as a remote monitoring tool for the power plant operators. User friendliness and high level of feature integration in the software components of iROSE and iRESS complete the system.

Acknowledgment

The paper is based upon work funded by Department of Electronics and Information Technology (DeitY), Ministry of Communications and Information Technology (MCIT), Govt. of India, under the Automation Systems Technology Centre (ASTeC) program implemented by the Control and Instrumentation Group of CDAC, Thiruvananthapuram. The authors would like to thank DeitY for extending their generous support and for funding this project. The authors would also like to thank Dr. Rominus Valsalam S, Group Head, Control and Instrumentation Group, CDAC, Thiruvananthapuram, for giving an oppurtunity to present this paper. Special thanks to Smt. Latha B Kaimal, Smt. Sindhu R and Smt. Lancy Thomas of Control and Instrumentation Group, CDAC, Thiruvananthapuram, for their whole hearted support and encouragement.

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