Dynamic model of heat ventilation and air conditioning (HVAC) system

Srinivas M* and Swarup K S**

This paper describes the implementation of SCADA to the HVAC (Heat Ventilation and Air conditioning) system, which is one among physical systems present in the spent fuel storage facility. The spent fuel storage facility contains the large number of equipment and control devices to maintain the facility critical parameters in the permissible limits. The mathematical model of HVAC system is done to monitor the critical parameters like temperature and humidity with respect to zone conditions. Over time both the radioactivity and the cooling requirements decrease and these parameters are to be monitored and controlled. The work projects deals the implementation of SCADA system to the spent fuel storage facility and monitoring of the critical parameters, the alarms to be generated for the abnormality situation. The scope of the work covers the SCADA design, modelling and monitoring of the critical parameters of the HVAC.

1.0 INTRODUCTION

Storage of irradiated nuclear fuel rods in water pools has been a standard practice since the inception of nuclear power generation. Pool storage is the starting point for all other fuel storage candidate processes. Storage of spent nuclear fuel in water pools is an interim measure, originally planned to culminate in fuel reprocessing after few months or years of pool residence. Recently environmental and political considerations have placed the availability of reprocessing units in dilemma, prompting increased stress on development of interim fuel storage options. Spent fuel storage is one of the important areas in the nuclear power plant [1,2]. The spent fuel assemblies are kept in racks in the pool, and water is circulated to provide cooling of fuel decay heat, mobility for easy fuel transport, shielding against radiation, visibility for fuel inspection [3,4].

2.0 LITERATURE REVIEW

There are so many critical parameters in the spent fuel storage facility like pool temperature, water pool level, pH of the water present in the pool, and radioactivity levels are to be monitored and controlled. Manual monitoring is not possible in the spent fuel storage, so we need automatic control system [5,6] is required to maintain the system in safe limits. SCADA stands for Supervisory Control and Data Acquisition, is a software package used in receiving the data from the remote sensors and takes control actions necessary.

Fundamentally, the most important issue of HVAC system factories was to keep the zone conditions in predefined values related to machines and human thermal comfort. The designers started to modelling and design of new type of HVAC system

*,**Department of Electrical Engineering, Indian Institute of Technology, Madras, Chennai - 600 036.

components with respect critical constraints in spent fuel storage like behaviour of spent fuel rods, and closed environment of the zone. Some study has been focused on HVAC modelling [11]. A Parvaresh, S M Ali [12] have used heat transfer and energy balance principles to identify a linear model to represent a non-linear model of a cooling coil. M. N. Lakhoua [13] has presented a transient model for a HVAC system for some components such as humidifier and mixing box, but no specific model for cooling/heating coils was given. Groszcsyk [14] provided a model for cooling coil with empirical parameters under the assumptions of constant air flow and water flow. Lizawati Binti Jaafar [15] presented two cooling coil models that were too complex and iterative computations.

In the process of modeling of HVAC system, Simulink was chosen, which is a larger degree of flexibility, modular structure, and the transparency of the modals and ease of use in the modeling process. The modular structure in Simulink makes it easier to keep an overview of the models, and new models can just as easily be added to the pool of existing models [12].

3.0   SCADA AND ARCHITECTURE

SCADA, as the name indicates, it is not a full control system but rather focuses on the supervisory level [7]. It is a purely software package that is positioned on top of hardware to which it is interfaced. It is an application that gets data about a system in order to control that system. It is a system operating with coded signals over communication channels [8] so as to offer control of remote equipment. The supervisory system may be integrated with a data acquisition system by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions [9]. It is a type of industrial control system (ICS). Industrial control systems [10] are computer-controlled systems that monitor and control industrial processes that exist in the physical world. It has two elements,

1.   Process/ equipment/ system to be monitored

2.   Network of intelligent devices, gives the ability to measure and control the first system

Figure 1 shows the basic architecture of SCADA for the spent fuel storage facility is designed based on the type of signals to be monitored.
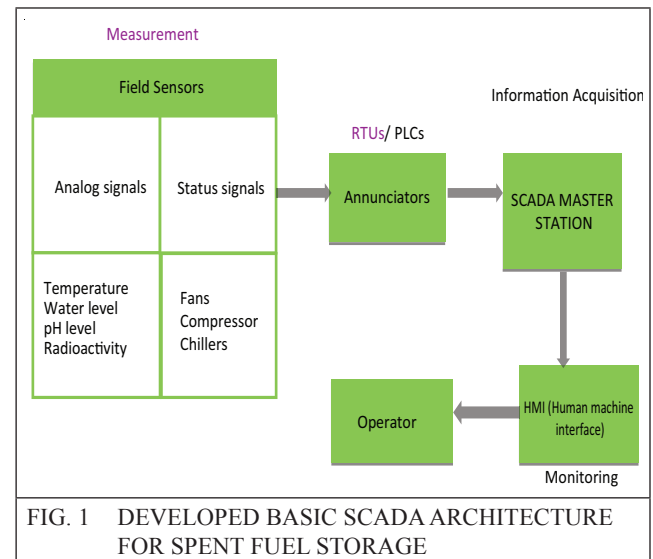

FIG. 1   DEVELOPED BASIC SCADA ARCHITECTURE FOR SPENT FUEL STORAGE

4.0   MODELLING OF HVAC COMPONENTS

Nowadays, several numerical simulation models for HVAC systems performance are being developed. Our scope is to design the HVAC components based on the dimensions and various unique factors involved compared to normal commercial buildings. Huge complexity is involved in the theoretical approach of formulating model. In order to develop full dynamic model of HVAC system we have to reach all of the important models of components. The major equipments considered in the facility are divided into two groups, which are zone model and the components of HVAC. Initially we proposed a model for the zone and later for all the equipments that are there in the in HVAC system

i.   *Zone model*

One of the most important sections of the HVAC system is the zone modeling. All of the components in HVAC system are to work to the zone to maintain to optimal conditions. In our

suggested HVAC model, we have considered the effect of uncontrolled input such as radiation of spent fuel rods, lights and heat dissipated by various equipments and so on and the effect of walls on the zone temperature. We have assumed the eight state variables, zone temperature, and temperature of each wall, zone humidity.

With these descriptions, the energy and mass balance equation [12] are,

$$C_z \frac{dT_z}{dt} = f_{sa}\, \rho_a C_{pa}(T_{sa}- T_z) + H_{ws}A_{ws}(T_{ws}-T_z) + H_{wn}A_{wn}(T_{wn}-T_z) + H_{we}A_{we}(T_{we}-T_z) + H_{ww}A_{ww}(T_{ww}-T_z) + C_0\frac{dT_o}{dt}$$
....(1)

$$C_{ws}\frac{dT_{ws}}{dt} = H_{ws}A_{ws}(T_{ws}-T_z) + H_{ws}A_{ws}(T_0-T_{ws})$$ ....(2)

$$C_{wn}\frac{dT_{wn}}{dt} = H_{wn}A_{wn}(T_{wn}-T_z) + H_{wn}A_{wn}(T_0-T_{wn}$$ ....(3)

$$C_{we}\frac{dT_{we}}{dt} = H_{we}A_{we}(T_{we}-T_z) + H_{we}A_{we}(T_0-T_{we}(4)$$ ....(4)

$$C_{ww}\frac{dT_{ww}}{dt} = H_{ww}A_{ww}(T_{ww}-T_z)+H_{ww}A_{ww}(T_0-T_{ww})$$ ....(5)

By calculating the above equations, the transfer function of the model is

$$G_z(s) = \frac{1}{C_z\, s+2\alpha}$$ ....(6)

Where $= f_{sa}\ \rho_a C_{pa} + H_{ws}A_{ws} + H_{wn}A_{wn}+ H_{we}A_{we}+ H_{ww}A$

ii. Cooling coil model

The increased emphasis on the variable working of HVAC equipment warrants a great understanding of the dynamic behaviour of cooling coils.

$$\frac{dT_{a,out}}{dt}=\alpha(T_a-T_t)-\beta\,(T_{a,out}-T_{a,in})$$ ....(7)

Where $Ta = \dfrac{MaCp,aTa,in + MwCwTa,out}{MaCp,a + MwCw}$

$$\beta = vM_a/\rho AL_c$$

$$W_z(s) = G_{wz}(s)W_s(s)$$

$$G_{wz}=\frac{fsa}{Vz\,s + fsa}$$ ....(8)

iii. Mixing box model

The mixing of air streams is a common practice in air-conditioning systems and it usually occurs under steady and adiabatic conditions. Figure 2 shows the mixing box model for for modelling and simulation of Spent Fuel Facility.

In this work, it is assumed that no frictional losses occur across the converging section.
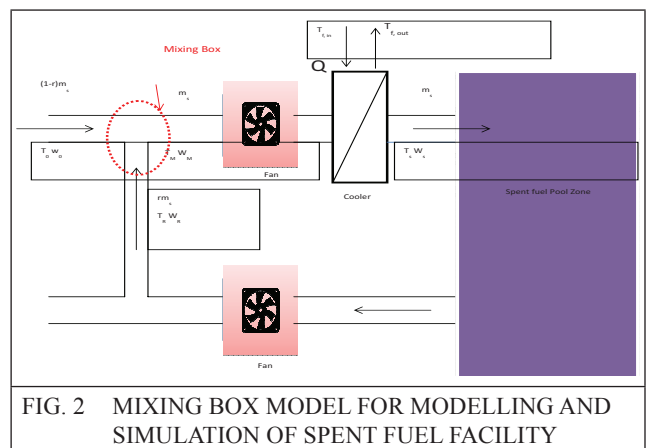

FIG. 2   MIXING BOX MODEL FOR MODELLING AND SIMULATION OF SPENT FUEL FACILITY

The maximum amount of air is circulated between inlet and outlet through suction fans and exhaust fans. The usage of external air is less compared to internal recirculation of air due to possibility of leakage of radiation.

The energy and mass balance equations are as below

$$m_r C_{pa}T_r + m_o C_{pa}T_o = m_m C_{pa}T_m$$ ....(9)

$$m_r + m_o = m_m$$

where, $\quad Tm = \dfrac{MrTr+MoTo}{Mr + Mo}$)

iv.   Duct model

The ducts are used in HVAC systems to deliver and remove air. Air ducts are one method of ensuring permissible indoor air quality as well as thermal comfort.

$$T_o(s) = G_{duct} (s) T_{in}(s)$$

$$Gduct(s) = \frac{}{+s}$$

$$T_{s,temp}(s) = \frac{s,temp}{s,temp+s}T_{m,temp}(s)$$

...10

v.   Working model of HVAC system

On integrating the each component model in the HVAC system of the spent fuel storage facility, we obtained the model below with consideration of certain assumptions. The simulation model is developed for the working layout of the HVAC system in the facility is shown in Figure 3.
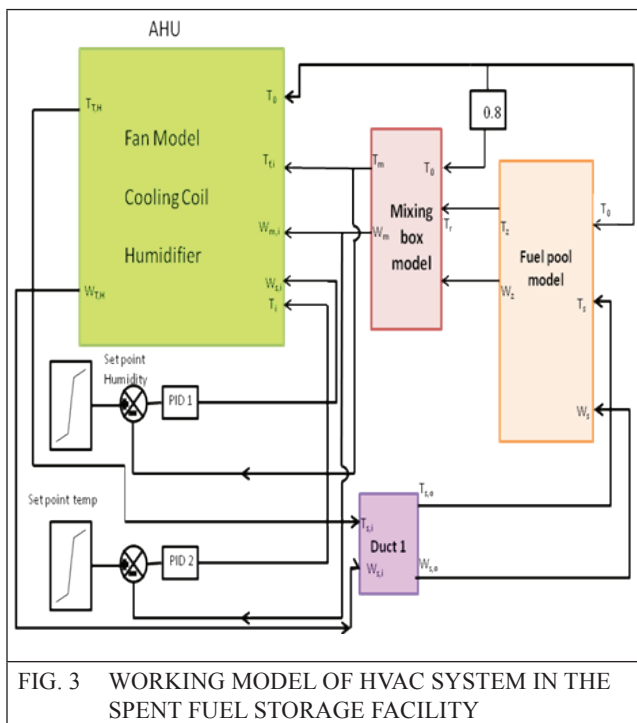

FIG. 3   WORKING MODEL OF HVAC SYSTEM IN THE SPENT FUEL STORAGE FACILITY

The main continuous parameters to be monitored from the model are air temperature and the water level of the pond. The logic sequence for the controlling operation of the HVAC system is done.

5.   SIMULATION OF HVAC MODEL

The simulation model is developed using Matlab /Simulink by using the equations of each component.
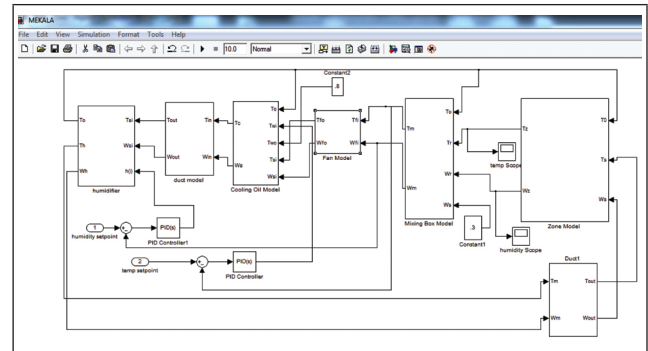

FIG. 4   SIMULATED MODEL OF HVAC SYSTEM IN SPENT FUEL STORAGE

The time domain equations are converted into S- domain Laplace transform and are used in the simulation model. Figure 4 shows simulink-model of HVAC system in spent fuel storage. The model contains the components like duct, cooling coil, and mixing box, and humidifier and fan model. Each component is arranged based on their real models. We considered two PID controllers for the control loops. We applied output temperature and relative humidity to the suggested model.
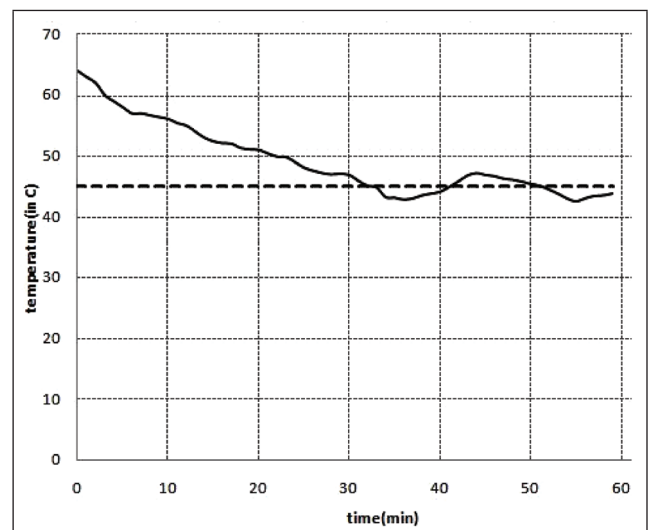

FIG. 5   ZONE TEMPERATURE – TIME CURVE OF THE PROPOSED MODEL.

Figure 5 shows zone temperature time curve obtained for the simulation model. It can be observed that the zone temperature tracks the

set point very well, at 33min arrived to desired temperature. The desired reference temperature is taken as 450C. The time constant of each component is taken as unity. By adjusting the time constants of the different components present in the system, the system can be made fast.
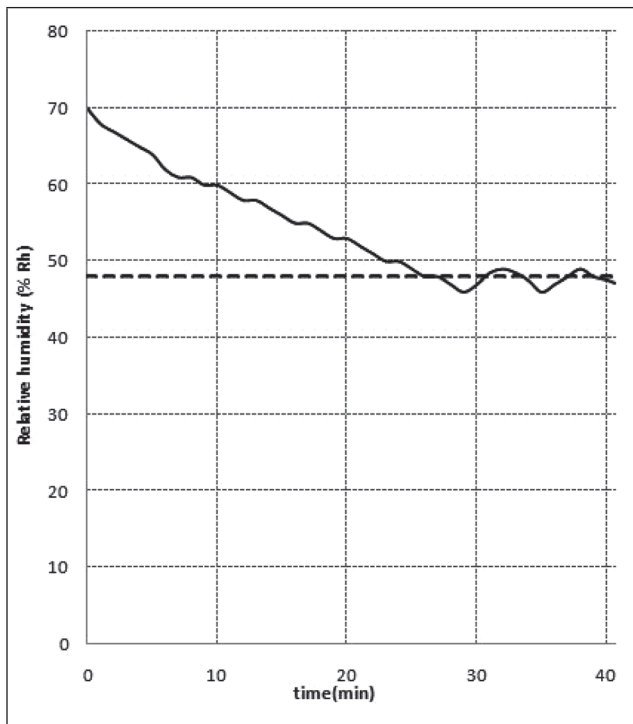

FIG. 6   RELATIVE HUMIDITY – TIME CURVE FOR THE PROPOSED HVAC MODEL

Figure 6 shows relative humidity time curve obtained from simulation. It can observed that suggested model tracks the set point with less time constant and high speed. The reference relative humidity is considered as 48 % Rh. The relative humidity settles after 28 min which is faster compared to zone temperature of the facility.

6. CONCLUSION

A dynamic model for HVAC components such as the zone, cooling coil, duct, humidifier, and mixing box, and the sensor is proposed. After the modelling of each component, we analysed simulation system of the complete HVAC SCADA system in Matlab/Simulink. In this model so far done, several simplifier assumptions such as floor area, behaviour of spent fuel, have been considered. But we presented a model for HVAC system can work well in the real system.

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