Thermal Power Control System in Solar Heaters: A Review

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ABSTRACT

As the solar radiations are the major source of renewable energy which is know is being used at large extent because of its plenty of availability. Due to availability of enormous energy through solar radiations the transferred energy into heat is to be controlled by some method, hence thermal control system is system to control the excess heating of the device and the material under process. As per the ongoing research a threshold value is being used of the ON/OFF strategy of the solar heaters to protect them from extra heating and the on the basis of the threshold value the starts or stops working. Thermal control system for solar heaters increases the efficiency of the heaters in terms of the heating energy conservation and the user comfort level. In this paper provides a review of different models for thermal control in solar heaters which works on different approaches and architecture.

Keywords- *ANN, Solar Radiation, Temperature, Thermal Control, Threshold, tramsmittence.*

I. INTRODUCTION

Solar water heating (SWH) is the conversion of sunlight into renewable energy for water heating using a solar thermal collector. Solar water heating systems comprise various technologies that are used worldwide increasingly. In a "close-coupled" SWH system the storage tank is horizontally mounted immediately above the solar collectors on the roof. No pumping is required as the hot water naturally rises into the tank through thermosiphon flow [1]. In a "pump-circulated" system the storage tank is ground- or floor-mounted and is below the level of the collectors; a circulating pump moves water or heat transfer fluid between the tank and the collectors.

In the paper section II will describes various thermal control models for solar heaters and the sub-sections are organized as, section A will describe the “Reference Model” [2] uses the current measurement of the horizontal global solar radiation as the prediction value for the six following hours. Sub-section B describes “Linear Model (AX/ARX)”[4] is the class of linear adaptive models of thermal control in solar heaters, least square method or the least square process is used to estimate the parameters for the model. Sub-section C describes the “Stochastic Model (STO)”[3][18] for the prediction of the climatic (solar radiation and outside air) or the frequency of the energy emitted by the source has been previously used in the predictive heating controller which was represented and tested successfully at LESO[19], Sub-section D describes the “Dynamic Programming Optimal Control Algorithm” [5][6][7] which optimizes the thermal comfort of the user and also optimize the energy consumption on a fixed time horizon.

A cost function is being incorporated in the model for the purpose of optimizing the energy consumption and the thermal comfort, Sub-section E will describes the “Thermal Management with Phase Change Material[13]” in which thermal control unit (TCU) has lot many features which can fulfill the cooling needs of the portable devices as electronic device for few hours. The TCU consists the phase change material and a thermal conductivity enhancer. Sub-section F will describes the "External Temperature Prediction Model [10]" The external air temperature has been considered as second major source for comparison in similar type of work. The available are considered for the data 1,2,3,4,5 and 6 hour, the testing for the prediction process of the external air is done with less details and section III will conclude the overall review.

II. VARIOUS THERMAL CONTROL SYSTEMS

A review of certain thermal control systems is being discussed in the section literature review and the different methods or processes are defined as the extension of one to another. The discussed algorithm differs in way that they have incorporated the factors of the device and also according to the architecture of systems.

A. REFERENCE MODEL (REF)

The reference model REF1 [2] uses the current measurement of the horizontal global solar radiation as the prediction value for the six following hours; the reference model REF2 takes the atmospheric transmittance, i.e. the ratio between the current measurement of the horizontal global radiation and the extraterrestrial value of the horizontal global radiation [2], as the prediction value for the six following hours. During the night, the atmospheric transmittance is not defined and therefore the average value over the last hours of the previous day is considered as predicted value.

B. LINEAR MODEL (AR/ARX)

The automated regressive AR and ARX [4] prediction models are class of linear adaptive models of thermal control in solar heaters, least square method or the least square process is used to estimate the parameters for the model and the mathematical equation for the linear model is represented as under:

$$y(k) = \sum_{i=1}^{m} a_i . y(k-i)) + \sum_{i=1}^{m} \sum_{j=0}^{j} b_{ji} . u_j(k-j-i) \tag{1}$$

Where y represents the output factor and u represents the input factor of the linear model, a_i and b_{ji} are the model parameters and m and o_{ij} are the order parameters of the linear model. The AR1 model with respect to the automated regressive model of the order of 2 which takes horizontal solar radiation into the consideration with a time stamp of k and k-1 as the input parameter. The prediction process in the linear model is considered upto six successive hours, hence while the prediction process of six hour ahead the estimated values of the past time steps are being considered as the input parameter for the linear model.

The changes that have done in the linear model ARX2 are that the model uses the horizontal global radiation of 24 hours ahead as the input for the linear model process, while considering the periodic characteristic of the meteo into consideration. Both linear models ARX1 and ARX2 are similar to one another with the factor of using the horizontal global solar radiation as the input parameter for the process.

C. *STOCHASTIC MODEL (STO)*

Stochastic model [3] for the prediction of the climatic (solar radiation and outside air) or the frequency of the energy emitted by the source has been previously used in the predictive heating controller which was represented and tested successfully at LESO. Solar radiation and the outside air are considered as the relevant parameter and are discretized into 10 different classes, which is thus used as 10 x 10 Markov probability transition matrices.

For the purpose of comparison between the probability which generated by stochastic model and reference model two different modes are being incorporated as linear mode and the neural network mode. The stochastic model for climate prediction is derived into two as STO1 and STO2, where STO1 predicts or generates the future transmittance by the process of selected the most probable value from the past data, while the STO2 model defines or generates the future transmittance by averaging the data received in past or data which is being gathered by considering the transition probabilities as weighting factor.

D. EXTERNAL TEMPERATURE PREDICTION MODEL

The external air temperature has been considered as second major source for comparison in similar type of work [10]. The available are considered for the data 1, 2, 3, 4, 5 and 6 hour ahead as:

- A reference model (REF1) [2] which considers the current measurement of external temperature as the prediction factor the successive six hours,
- Two auto regressive models (ARX1 and ARX2),
- Two artificial neural network models (ANN1 and ANN2),

The testing for the prediction process of the external air is done with fewer details as in all the following models of prediction the external temperature is considered less important then the other factors as the solar radiation. For well insulated and heavy buildings the impact of the external air or the instantaneous variations of the external air or temperature is less than what of solar radiations is represented in the table 1.

TABLE 2.1: The standard deviation of the prediction error of the external temperature l, for time horizons from 1 to 6 hours, in [°C]

	1 Hrs	**2 Hrs**	**3 Hrs**	**4 Hrs**	**5 Hrs**	**6 Hrs**
REF1	0.50	0.82	1.10	1.34	1.55	1.73
ARX1	0.45	0.69	0.89	1.06	1.21	1.35
ARX2	0.44	0.67	0.85	1.02	1.19	1.35
ANN	0.45	0.45	0.92	1.07	1.18	1.31

E. DYNAMIC PROGRAMMING OPTIMAL CONTROL ALGORITHM

Dynamic Programming Optimal Control Algorithm [5][7][8] optimizes the thermal comfort of the user and also optimize the energy consumption on a fixed time horizon. A cost function is being incorporated in the model for the purpose of optimizing the energy consumption and the thermal comfort.

The mathematical expression of the cost function used for the NEUROBAT controller is described hereafter:

$$J(U,T)=Cu + U + Cp + (\exp(PMV_2)-1) \qquad (2)$$

Where U represents the heating command, PMV (T) depicts the predicted mean vote on the Fanger's scale, T is the comfort temperature, Cu is the heating coefficient for the energy term and Cp represents the weighting coefficient for the thermal discomfort term.

Equation 1 represents the complete description of the cost function for optimizing the energy consumption and the thermal comfort. Two terms in the expression are heating energy consumption and the thermal discomfort by the average users. PMV (Predicted Mean Vote) is the thermal discomfort as given by the Fanger's formalism.

The correct weighting of the two cost function terms is achieved by using a simple heuristic rule: "The cost of the energy consumption which is needed to compensate a 0.2 variation on the PMV is equal to the cost of the discomfort resulting from that same PMV variation." That rule takes into account the effective thermal capacity of the building (or of the considered room). If we fix an arbitrary value of Cp equal to 1 (only the ratio between Cu and Cp has significance), then the value of Cu is given by the expression below:

Cu = t+k+(exp(PMV_2)-1)/(Cdyn + PMV) (2)

Where Δt represents the time interval during which the heating power is applied [s], k depicts the linear constant for the PMV linear approximation PMV = k · (T - Topt), T is the room temperature [°C], Topt is the room temperature for the optimal thermal comfort (PMV = 0) [°C], Cdyn represents the effective (dynamic) thermal capacity of the room [J/K].

F. THERMAL MANAGEMENT WITH PHASE CHANGE MATERIAL

A thermal control unit (TCU) [13] has lot many features which can fulfill the cooling needs of the portable devices as electronic device for few hours. The TCU consists the phase change material and a thermal conductivity enhancer. The main functionality of the thermal change material is to absorb the heat generated by the heat source in the device during the working condition releasing the same at OFF state. The releasing of heat absorbed keeps the surface temperature of the device at low level and keeps the comfortable level of user's skin.

The electronic outer surface temperature is relatively low and comfortable to the user's skin. The TCE is used to make the melting and freezing of the PCM uniform. Once the component temperature reaches the PCM melting temperature, the PCM melts and absorbs heat until it is completely melted. During this period, the component temperature is almost constant and a steady state temperature is delayed, allowing additional operating time before reaching the component's maximum temperature. Relatively high amounts of energy can be stored in small quantities of PCM because of the latent heat of the PCM.

Leoni and Amon [13] built a numerical model for the TCU, with the objective of investigating the performance of the TCU under different geometry layouts and the effect of using PCMs with different melting temperatures. The TCU is embedded in epoxy polymer [7] that simulates an electronic device embedded in a wearable computer [8], and a heat source unit is attached to the thermal control unit. To control the temperature for a specific electronic component, completely enclosing the heat source component by the thermal control unit is recommended for best performance. Experimental and numerical investigations were performed by Vesligaj and Amon [13].

The physical experiments were conducted to study the performance improvement by introducing a PCM thermal control unit into an electronic device model. The numerical calculations predict that the TCU can improve the system's performance during time dependent operating conditions by dampening the heat source temperature fluctuations during PCM melting. The boundary conditions and thermal conductivity of the polymer composite substrate have a significant effect on the TCU's performance because they affect the heat path in the system.

Table 2.2: Parametric comparison of different approaches for thermal control with respect to the standard deviation for the prediction error.

	1 hrs	**2 hrs**	**3 hrs**	**4 hrs**	**5 hrs**	**6 hrs**
REF1	**66**	**114**	**149**	**168**	**171**	**161**
REF2	**43**	**68**	**88**	**103**	**109**	**110**

ARX1	**46**	**73**	**87**	**93**	**94**	**93**
ARX2	**47**	**64**	**77**	**86**	**91**	**93**
STO 1	**48**	**48**	**70**	**89**	**111**	**115**
STO 2	**43**	**62**	**77**	**89**	**96**	**100**
ANN	**43**	**58**	**71**	**78**	**83**	**83**

TABLE 2.3: Description of the various commercial and NEUROBAT heating controllers used for the simulation.

Controller	**Sensors**			**Control Concept**	**Remarks**
	Outside temp	**Inside Temp**	**Solar Rad.**		
REF(Standard Commercial Controller)	YES	NO	NO	open loop control referenced to the external temperature	common control system; not well suited for buildings
ARX (Performant Commercial Controller)	YES	YES	NO	variant 1 + adaptation to inside temperature and optimal start/stop	suitable for buildings with intermittent operation
STO Controller	YES	YES	YES	variant 2 + adaptation to solar radiation	solar gains taken into account
Dynamic Programming Controller	YES	YES	YES	optimal control + ANN models	basic variant

III. CONCLUSION

In this paper a review of various thermal control strategies is being discussed on the basis of several parameters and also a brief discussion of view of the algorithms. Thermal control in solar heaters is the major research topic because of growing use of solar radiation as the major source of energy for day to day need. Thermal control means the controlling the overheating the device or the application material by defining a threshold temperature after which the system stops working. Some model uses material change technic to control the overheating. From the review of various algorithms or models for thermal control in solar heaters the process of decision for ON/OFF strategy of the system should also include various past parameters such as solar radiation frequency, internal temperature or building behavior and also the user comfort with time.

IV. REFERENCES

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