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CONTROL SYSTEM STUDY FOR AGRICULTURE GEOTHERMAL UTILISATION IN THE ELHAMMA REGION-TUNISIA

Lassaad Ben Brahim Sbita[1] and Johan Thor Magnussson[2]
[1]Ecole Nationale d'Ingénieurs, Gabès 6029 ENIG, Tunisia
[2]Rafhonnun consulting engineers, Armula 42, 108 Reykjavik, Iceland

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ABSTRACT

The paper describes the dynamic simulation of a complete typical geothermal project in El Hamma region in Tunisia, including well, tank, water distribution, greenhouses and connection with the oasis irrigation. It presents a design study based on dynamic simulation focusing on the development of control systems for a geothermal utility installation for a greenhouse heating and cooling and oasis irrigation project. The aspects of modelling, simulation and development of a control system for this kind of project are then presented. Thereafter, the technical subsystems, namely, geothermal water production and distribution, and greenhouse climate control are described. Field data are used to substantiate the simulation runs. This paper demonstrates that simulating the geothermal installation and its computer control systems is a realistic and useful step in a pre-feasibility and management study for a project of this kind. One key finding of the simulation work is that the greenhouse area can potentially be doubled through the addition of a buffer tank and suitable control equipment.

1. INTRODUCTION

Tunisia, a Mediterranean and North African country, has rapidly developed mainly tomato and melon production in greenhouses heated and irrigated with geothermal water. The development of this sector has been going on under adverse climatic conditions in the southern part of the country in arid and desert regions known for their lack of rain. In the El Hamma region deep wells were drilled by the government for irrigation purposes in oases and ventilated cascade towers are used for cooling. Creating geothermally heated greenhouses close to an oasis system is complicated and needs careful planning and studies based on many aspects such as the choice of the appropriate site and the organisation and arrangement of the greenhouse projects. Water demand for heating greenhouses and irrigation purposes in oasis and greenhouses is gradually increasing due to the extension of greenhouse projects and increased oasis agricultural renovation. In order to avoid waste of water resources which are considered non-renewable and very valuable in this region, a considerable effort is needed to optimise geothermal water direct use. The development of geothermal greenhouses in this region is the result of several historical and technical steps. Late in the seventies and during the eighties, a large amount of low-enthalpy water from geothermal wells was identified. These wells were drilled mainly for irrigation purposes by the Government. Due to the lack of rain in this southern part of the country, this area is considered an arid zone with a natural water deficiency preventing normal crop development. However, the Government drilled many deep wells to exploit these geothermal resources for complementary irrigation in oases where the date palm is the most dominant crop. The geothermal water used for irrigation is generally cooled by ventilated atmospheric cooling towers. As in most sub-Mediterranean countries, obtaining early crop production and the good product quality needed for export was very difficult without heating, because during the winter the minimum air temperatures were mostly below 7°C and, particularly, lower than 5°C in this desert region. Therefore it was proposed to use geothermal water in the southern regions for heating greenhouses, to raise the air temperature from about 7-8°C to a minimum of 12°C. Several experiments have been carried out since 1983 by the National Agronomic Institute of Tunis. In 1985, the United Nations Development Project was created (UNDP-TUN/85/004) with the object of promoting production in greenhouses for export by using geothermal resources for heating and irrigation. At present about 95 ha of plastic greenhouses heated by geothermal water are in production, making Tunisia third ranked in the world for this technology after the United States and Hungary.

The government and the private sector are both involved in the capital investment of the project. Each one has a role and responsibility to ensure efficient use of geothermal resources in the country. However, accurate analysis and technical solutions are required if more geothermal greenhouse projects in cascade with the oasis irrigation are to be completed. This study is a contribution to the development of an optimal control technique for the whole system from the production well to the end water use. This paper introduces the process and control system shown diagrammatically in Fig. 1. The dynamic modelling of the different subsystems of the project are then described. Finally, some results are given to illustrate the simulation runs. A general conclusion is reached at the end.

2. DYNAMIC MODELLING OF THE GEOTHERMAL PROJECT

2.1 Greenhouse dynamic model

In this section a greenhouse climate dynamic model is proposed. This model incorporates the effects of natural ventilation, geothermal water heating and the evaporative cooling process as climate control parameters. In a previous study Souissi and Sbita (1996) presented the reduction of the complete thermodynamic model of a greenhouse to a reduced single static well adapted to the control implementation schemes. Here, a reduced dynamic model takes into account a virtual thermal mass compartment corresponding to the greenhouse structure plus the soil and the vegetation which

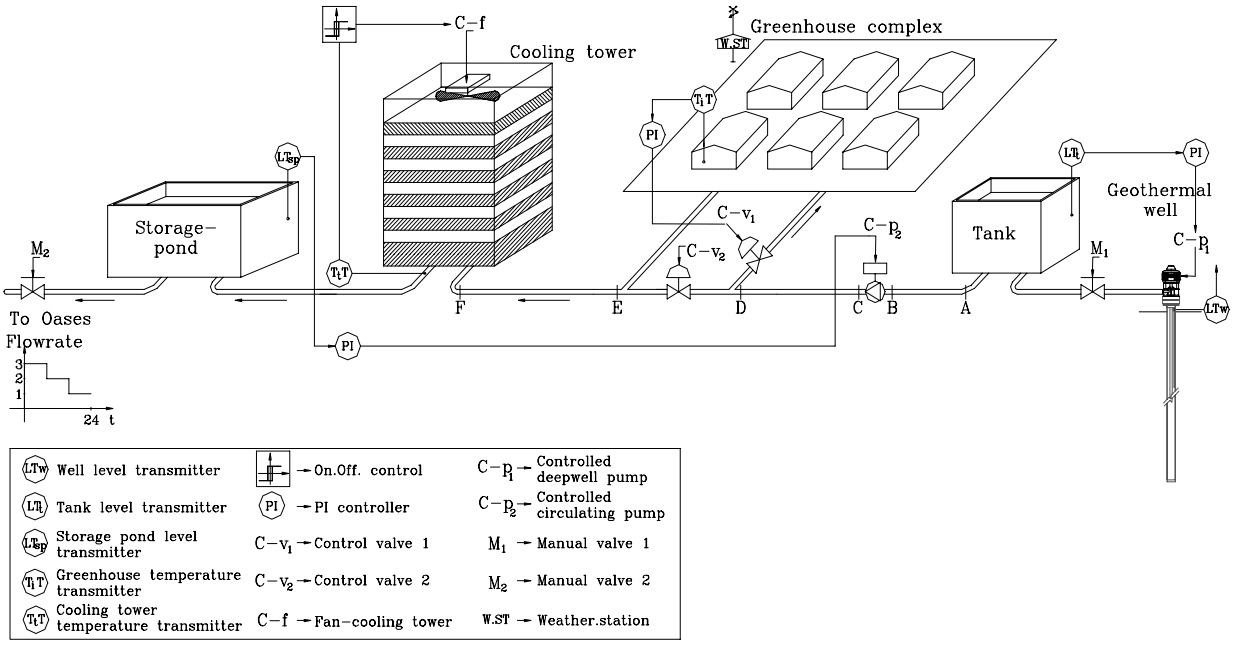


Figure 1. Schematic representation of the proposed geothermal project with control systems

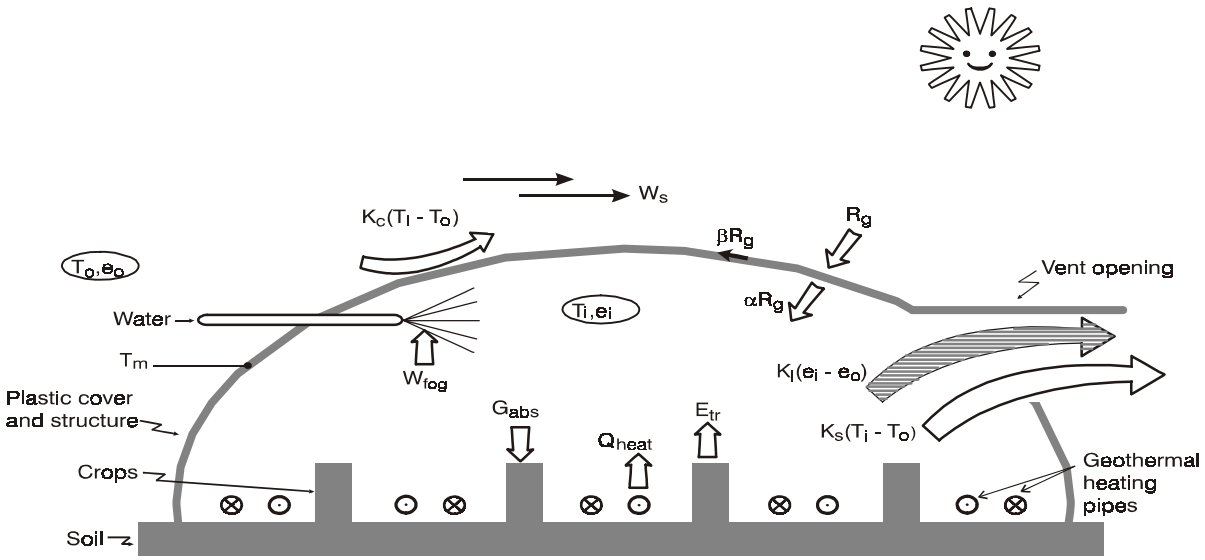


Figure 2. Schematic of elements and energy flux of the greenhouse

are characterised by the temperature $T_m(°C)$ and the thermal capacity $C_m(J/°Km^2)$. The inside air is characterised by the indoor temperature $T_i(°C)$, the actual water vapour pressure $e_i(hPa)$, the water vapour thermal capacity $C_l(J/°Km^2)$. Fig. 2 shows the different energy fluxes and compartments used in this model. The mass and heat balance equations are given as follows.

The heat balance of the greenhouse thermal mass is

$$C_m \, dT_m/dt = \beta \, R_g + Q_{heat} + h \, \Delta T_m \quad (1)$$

where
$Rg(W/m^2)$ is the global solar radiation flux
$h(W/K.m^2)$ is the convective exchange coefficient between the indoor air and the thermal mass
β is solar radiation absorption coefficient of the thermal mass
$\Delta T_m(°C)$ is the difference between T_m and T_i

The greenhouse indoor air heat balance

$$dT_i/dt = C_{air}[\alpha R_g + Q_{heat} - h\Delta T_m + (K_c + K_s)\Delta T + K_l \Delta e] \quad (2)$$

$To(°C)$ and $eo(hPa)$ are respectively the outside temperature and actual water vapour pressure. $\Delta T(°C)$ is the difference between T_i and T_o and Δe (hPa) the difference between e_i and e_o.
$Q_{heat}(W/m^2)$ is the energy flux from the heating radiator. The overall heat loss coefficients are $K_c(W/°K.m^2)$ through the cover, $K_s(W/°K.m^2)$ sensible and $K_l(W/hPa.m^2)$ latent ones due to weather and ventilation flux. These last fluxes are widely studied in a previous paper (Sbita, 1998).

The Water vapour mass balance

$$C_l \, de_i/dt = K_l \Delta e - E_{tr} - W_{fog} \quad (3)$$

where $E_{tr}(W/m^2)$ is the crop transpiration flux and $W_{fog}(W/m^2)$ is the energy flux of the cooling system sprayed water vaporisation (Sbita, 1997).

The heater emission

The radiators inside the greenhouse consist of many loops of corrugated polyethylene pipes. These radiators are designed following the Tichelman heating system (Harrison, et al, 1990). The total heat transfer across the radiator is considered as the sum of the heat transferred across each elementary loop. Each loop is a long tube carrying hot water and it can be divided into n elementary sections. Each of these parts is considered having a constant temperature of hot water and exchanging heat according to the temperature difference relative to the surrounding air. Then, an iterative calculation method permits the hot water outlet, and hence the total heat transfer, to be obtained from the measurement of the inlet temperature alone. For an arbitrary section number j the heat transfer is;

$$Q_{heat}(j) = A_{pipe}(j) \, K_{pipe} \, (T_w(j) - T_i) \quad (4)$$

The temperature of the water for the next $(j+1)$ section is

$$T_w(j+1) = T_w(j) - (Q_{heat}(j)/(q_w C_w)) \quad (5)$$

where
K_{pipe} is the overall heat transfer coefficient ($W/°Km^2$)
$A_{pipe}(j)$ represents the surface area of the pipe section number j (m^2)
and q_w and C_w are the water flow rate and the thermal capacity.

2.2 Cooling tower modelling

In this study area, the ventilated atmospheric cooling tower is the type that has been selected for cooling the hot water from the well for irrigation purposes. The cooled water collected at the bottom of the tower and its circulation to the oasis storage pond is facilitated by gravity. To control the temperature of the tower outlet water we used an on/off control electrical fan to accelerate the air circulation. For modelling, we divided the cooling tower into sections. Each section is a partial cooling tower cell, characterised by a heat transfer coefficient $K_{CTi}(W/°K)$.

The heat transfer at section j is

$$d\,h(j) = (T_w(j) - To(j))/K_{CTj} \quad (6)$$

Then we get the temperature drop

$$d\,Tw = dh(j)/(q_w C_w) \quad (7)$$

An iterative calculation method is then used to get the down stage cooling tower water temperature which is the cooling tower outlet temperature. The outlet temperature is used to control the fan action.

2.3 The tank and the storage pond

The storage pond for the oasis irrigation is very large. The design parameter is the storage capacity, which must be sufficient to store the water returned from the greenhouse heating system over three nights. Government approval was required for the installation of this type of storage pond. The oasis level is lower than the main geothermal installation. The geothermal tank is used as a buffer tank, and is designed for emergency to cover at least the longest heating duration, to cover the case of well pump failure and also to supply peak heating loads. It allows greenhouse area, which is currently limited by peak flow, to be doubled. The longest heating duration corresponding to the critical cold period is 12 hours.

3. SIMULATION OF THE CONTROL SYSTEMS

From the control point of view, the dynamics of the geothermal system are mainly due to the response of different parts of the system to changes in the hot water flow rate and external conditions such as the weather. This flow rate is a very significant parameter with respect to the geothermal well characteristics, to the use of the transported energy by means of heat exchange and in its effect on the pressure dynamics of the system components. Unfortunately the cooling tower causes a major waste of energy and pure water (evaporation estimated between 7 and 10%). The cascading

of the greenhouse project with the cooling tower therefore makes good use of energy otherwise wasted. The simulation method we used here deduces the water flow from integration of the system characteristic in a dynamic way. This means that each component of the whole installation and especially the actuators cause a change in the system dynamics at each decision step. The flow rate in each part of the system is then indirectly deduced using the previous iteration. From a control point of view the hot water system can be separated into two subsystems, the well plus the tank and the water from the tank into the oasis and greenhouses. As shown in Fig.1 and for the control system simulation, an iterative method has been used. The calculation of different flow coefficients monitoring the system is presented for each section as follows:

Section B-C: Here we have a variable speed circulating pump P_1 characterised by a flow coefficient K_{p1}. For rated speed and corresponding flow rate we have all the data to calculate the K_{p1} coefficient.

Section C-D and E-F: each of these two pipes is designed for its maximum flow rate. Therefore it is easy to get their coefficients K_{CD} and K_{EF}.

Section D-E: This section is composed of the greenhouse heating system and the two control valves. The control valve v_2 is in parallel with the control valve v_1 which is in series with the heating system. Suppose the heating system has a flow coefficient Kv_{Heat}. For this series connection the flow coefficient Kv_{SYS} is deduced. In the same way the parallel section D-E has a combined flow coefficient Kv_{DE}.

According to Fig.1, the system characteristic Kv_{total} permitting the total flow rate from the point A to F is:

$$Kv_{total} = Kv_{p1} + Kv_{CD} + Kv_{DE} + Kv_{EF} \quad (8)$$

For the production well and tank side, the system is composed of the variable speed well pump and a pipe line feeding the tank. The same procedure as described above is then used, with one closed loop control for the well flow rate, by controlling the pump production speed.

4. SIMULATION RESULTS AND DISCUSSIONS

A complete simulation programme was performed using the advanced simulation language "ACSL". This program allowed us to predict the performance of the control systems used for this geothermal project. Many results are available and could be extracted as far as the exploitation of the simulation runs is oriented towards a specific problem. In this section we limit ourselves to the main specific parameters we studied to demonstrate time variation behaviour of the control system.

4.1 Greenhouse climatic control

Here we dealt with the control of the greenhouse climate. Fig. 3 shows the outside climate conditions (measured data). These conditions correspond to typical weather between the cold period and the hot one (Sbita, 1997). In this paper the dynamic climate behaviour of the greenhouse was studied as a production unit which is characterised by a thermal and biological environment leading to heat and mass exchange through the structure of the greenhouse. The heat and mass transfer are related to the processes such as crop transpiration, natural ventilation, geothermal water heating, and evaporative cooling under the effect of the external conditions. The simulation runs provide the time variation of the modelled parameters. The modelled inside climate is characterised by the humidity and the temperature of the air. The variation of these parameters is supervised by the control system. The greenhouse control system design has technical and economical constraints, therefore it has to be simple and realistic. Therefore a *PI* controller is used to control the inside air temperature in the cold period, as shown in Fig. 1. This temperature control is designed for a complex of greenhouses as a lumped model. The hot water is supplied to the radiators through the greenhouse *Tap-Off* control valves. The data for the external factors (wind speed, relative humidity, outside temperature, etc.) is recorded by a weather station located in the greenhouse complex area. Fig. 3 shows the outside weather data measured at a production site in the studied area. This figure represents the outside humidity, temperature, wind speed and solar radiation variation. These parameters are considered as model inputs. For cooling the greenhouse and controlling the inside humidity the ventilation and evaporative cooling systems were used as control parameters. A specific *On/Off* controller was used to control the aeration and the evaporative cooling process. For the same input weather data, the controlled climate of the indoor temperature and humidity were simulated. The variation of these two parameters is illustrated in Fig. 4 with the controller actions on the ventilation opening and evaporative cooling injection. The simulation was performed for 24 hours starting at 6.00 p.m (corresponding to 0.0 on the time scale of the simulation plot). As shown in Fig. 4 the indoor temperature variation for a cool night (around 5°C) was controlled for a desired set point (13°C) by the PI controller of the heating system. The wind speed variation has a significant influence on the heat loss through the greenhouse plastic cover, generating a small variation due to the delay in the heating system response (geothermal water). The ventilation is simulated with an offset due to the leakage through the cover. This causes latent and sensible heat loss according to the ventilation flux even though the openings are closed. According to the simulation results it can be seen that the greenhouse works in the manner of a solar collector. The indoor climate is an amplification of the outdoor weather condition. The variation of the humidity and the temperatures inside and outside follow almost the same shape. The inside controlled parameters are limited by the outside condition in the ventilation cooling system. In this way, the evaporative cooling is an additive process having a favourable effect in conditioning both the humidity and the temperature variation (Hanan, 1998). The air inside the greenhouse in the semi-arid zone and in the hot period is characterised by a high water vapour deficit which effects the transpiration process of the crop. The evaporative cooling process is demonstrated as being the only solution for decreasing the water vapour deficit. During the day, under the solar radiation effect this evaporative cooling must be used in the control process as well as the natural ventilation, in order to avoid an increase of the temperature inside the greenhouse above the set point value.

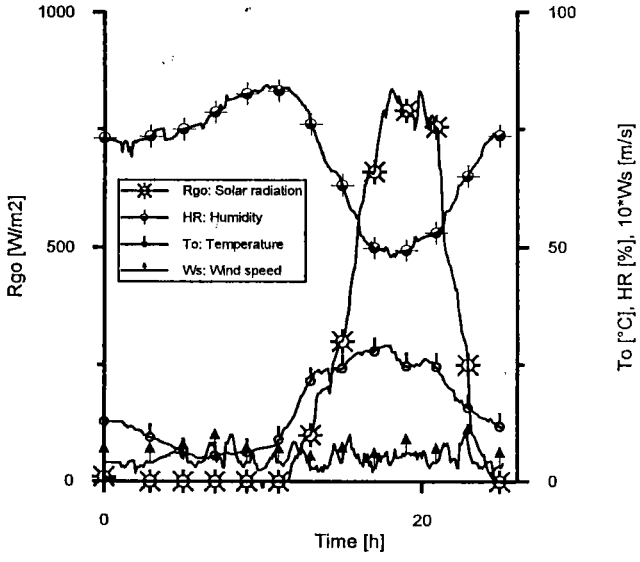


Figure 3. Greenhouse outdoor climate parameters

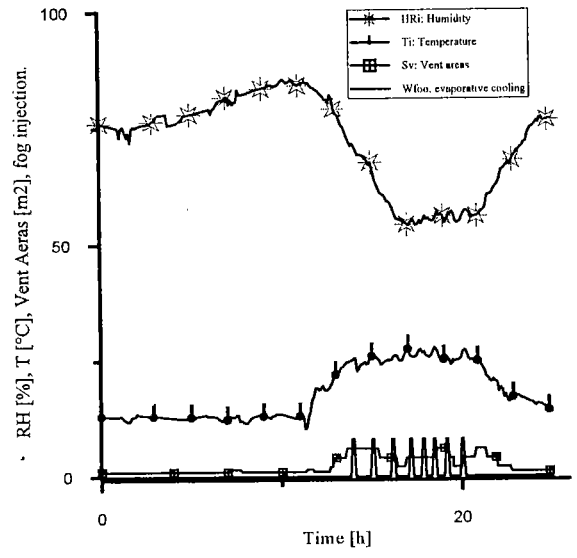


Figure 4. Greenhouse indoor climate control

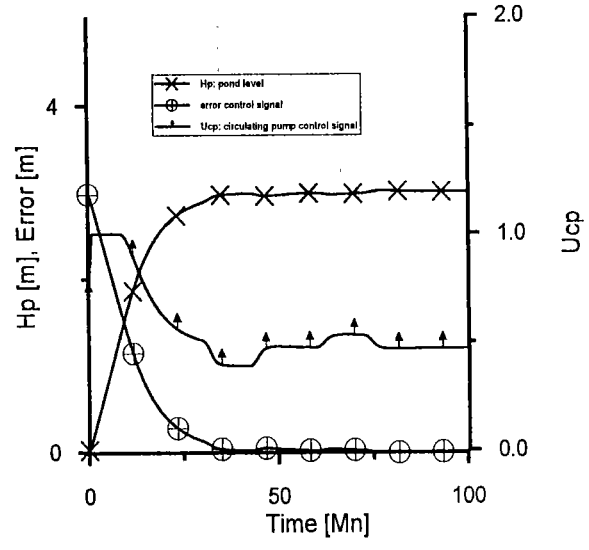


Figure 5. Water demand control

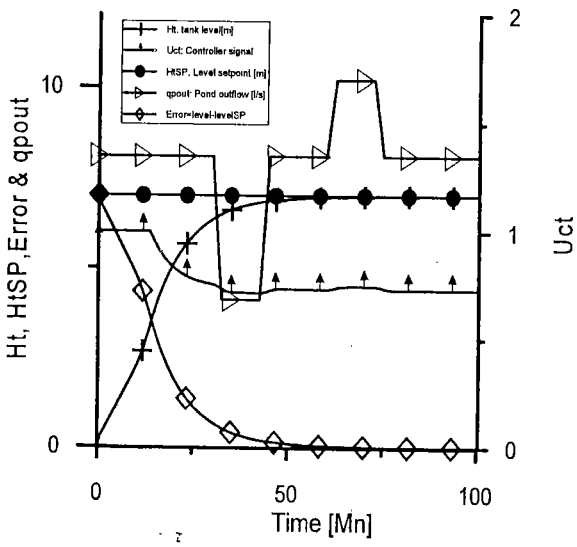


Figure 6. Water production control

4.2 Water flow rate control

The simulation of the control systems for the proposed geothermal project (Fig. 1) are considered here. The main control actions can be illustrated as the control of the geothermal water production flow rate, the water demand flow rate, the heating control of the greenhouse and the cooling tower outlet temperature. Thus the following paragraphs focus on aspects of the regulation of the whole process.

The design of the production and the water demand installation can be divided, from the control point of view, into two subsystems. As shown in Fig. 1, the buffer tank has the role of a separator between the production system and the water distribution system. The water flow control in these two subsystems is represented in Figs. 5 and 6.
In Fig. 5, a water demand fluctuation is applied as a system perturbation. The production system *PI* controller reacts by a control response of the well variable speed pump. The same figure illustrates the signal of the control error of the tank level due to the water demand. Fig. 6 represents the response of the water demand control system. According to the same water demand fluctuation the signal from the controller is applied to the variable speed circulating pump (Fig.1). The storage pond level response is more sensitive in this regard than the well-buffer tank. Fig. 6 also illustrates the variations of the controller response error showing the more significant fluctuations that affect the system response around the set point.

5. CONCLUSION

In this paper, it has been shown that process controls play an important role in a greenhouse and oasis irrigation project using geothermal resources. They are rather complex technological systems whose behaviour can hardly be studied fully without the aid of dynamic simulation models. It is also clear that process control of such a complex geothermal installation greatly benefits from the use of modern control systems, sound control knowledge and engineering development. This is because the process is an interconnected large scale one with distributed elements and a complex network. One of the key findings of the simulation work described in this paper is that the greenhouse area could potentially be doubled through the addition of a buffer tank and suitable control equipment. Solving technical problems in large geothermal installations requires considerable research and development effort. Advanced control principles should be applied if one is to ensure the most efficient utilisation of the geothermal energy resource. Moreover, certain process controls (greenhouse climate, resource distribution) are not solvable without the use of sophisticated methodologies. As far as the technical implementation is concerned, efficient measurement, signal and information processing, computing and actuator technologies ought to be used. A whole range of modelling, simulation and identification, as well as experimental studies have to be carried out. It is believed that the most adequate approach for the development of process controls in a geothermal project would be a top-down implementation with extensive use of computer aided techniques. In a large geothermal utility installation of this kind, including cascaded uses of geothermal energy, a distributed computerised control system with integrated information base and multilevel organisation of control functions should be studied.

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