Smart Control for Passive Greenhouses

Marius M. Balas, Valentina E. Balas
"Aurel Vlaicu" Univ., Arad, Romania
balas@inext.ro

Abstract

The paper is focused on a new passive greenhouse architecture, provided with cold water heat pumps, wind generator and solar panels. This greenhouse is independent of any energetic infrastructure (electric, gas, hot water). The sizing of each element and the automate control are critical in order to reduce the costs. A simplified mathematical model, able to assist the design and the automate control, is provided. A fuzzy-interpolative adaptive controller with internal model is introduced.

Keywords: energy-passive greenhouse, heat pump, wind generator, amorph silicon photovoltaic panels, fuzzy-interpolative controller.

1 Introduction

As anticipated by the reports of the Club of Rome in '70s, the human growth is now close to reaching its limits. The same technology that made possible an amazing growth of the human population, in terms of number and quality of life, is now irreversibly altering the natural environment. A global warming process is triggered. The cause of the warming process seems to be connected to the growing of the CO_2 concentration in the atmosphere, as consequence of burning huge amounts of fuel [1]. This is enhancing the glasshouse effect of the atmosphere, that is eventually heating the surface of the planet. Human technology that caused this complex problem has now the responsibility to solve it, by investigating solutions able to reduce the CO_2 atmospheric concentration and the greenhouse effect. A natural approach would rely on forestation, since trees' metabolism is demanding great quantities of CO_2 and is eliminating oxygen [2].

The purpose of our paper is to study a technology that is potentially able to support a massive ecological reconstruction, with a benefic influence on the CO_2 balance in the atmosphere. The basic idea is to reconvert a significant part of the present agricultural surface into natural environments, and to feed the human population using a drastically reduced surface, covered by energy-passive greenhouses.

2 The Passive Greenhouses

2.1. Introducing the Passive Greenhouses

The energy-passive greenhouses EPG are independent of any conventional energy source (gases, liquid fuel or electricity). They are relaying exclusively on alternative energy sources like sun, light, wind, geo-thermal waters, etc. Turning conventional solar passive greenhouses (simply heated by the sun and naturally ventilated) [3] into EPGs implies serious investments, but is offering instead the complete independence of the climatic conditions. An ideal passive greenhouse would use all the possible renewable energy resources, would be totally independent of any conventional energy sources and infrastructure and could be installed virtually anywhere on the surface of the earth.

Solar and wind energies are clearly the first candidates when coming to alternative energies [4] [5], but they are not disposable in any moment, their time evolution is extremely random. Questing for a renewable energy source that is permanently and everywhere disposable, we are discovering the geothermal energy. However the hot waters reserves are rare and usually located deeply underground, so the final choice will be the cold water heat pumps [6], [7]. Heat pumps are able to extract energy from low temperatures

L. Magdalena, M. Ojeda-Aciego, J.L. Verdegay (eds): Proceedings of IPMU'08, pp. 826–831
Torremolinos (Málaga), June 22–27, 2008

waters and inject it into closed water pipes heating installations. They were invented in XVIIIth century by Sadi Carnot but their price become feasible only two hundred years later, at the end of XXth century.

There are two constructive variants: either two water wells or an underground pipes web. The water extracted from the first well is introduced into the pump, where it leaves a part of its energy that is injected into the greenhouse, loosing several degrees of its temperature. An underground water circuit is created (extern or intern). During the underground circulation the water is rewarmed by the energy provided by the thermal radiation of the earth. This type of energy is available everywhere on the surface of the earth, it is not influenced by weather and it's free. The heat pumps still need a small external energy amount, in order to recirculate the water, but the energy balance is very favorable: for a heating power of 5-6W only 1W must be spent for the recirculation. The maintenance of this device is easier than the conventional heating systems', it has no safety or pollution issues, the only bottleneck appears at the exhaustion of the cold water, that might freeze when the external temperature is very low and no appropriate constructive solutions are provided.

We begun the study of the greenhouses/heat pump interaction in 2004 [8]. The same idea was applied in ref. [9] in 2007.

2.2 The Heat Pump/Wind Generator/ Solar Panels Aggregation

Aggregating several complementary energy sources (geothermal, wind and solar) ensures the independence of the weather conditions. The wind energy has some similarities with the geothermal one: it is available everywhere on the surface of the earth and free of any costs. On the other hand the wind is highly inconstant. However, if we will accumulate the wind energy and use it only for the heat pump's recirculation, the installed power of the wind generator can be 5-6 times smaller than if we would used it for direct heating. Another argument is pleading for the wind generators: the possibility to compensate the convection energy loses to the greenhouse's walls by the wind itself [10]. We decided to provide the greenhouse and with a group of orientable amorph silicon photovoltaic panels, in order to produce electrical energy and shadow the plants in the same time, when solar radiation is very high and the greenhouse would overheat. The supplementary solar energy will be also accumulated and will supply the greenhouse's equipment. The solar panels might seem expensive and luxurious at the first glance, but we find at least three reasons for their inclusion into the system:

- Their price is continuously decreasing;
- They are replacing the actual rolling curtain system, that is shading the plants when the solar radiation is too strong;
- They are making possible the use of smaller wind generators.

The structure of our passive greenhouse is presented in fig. 1.

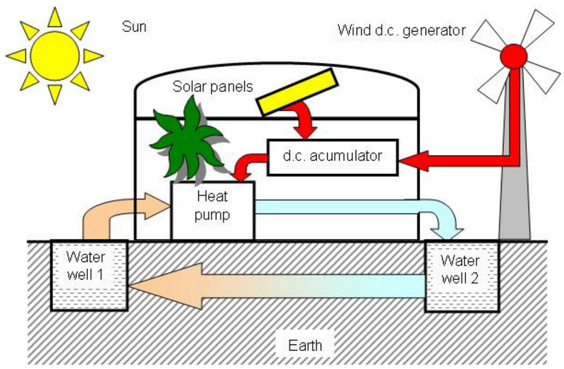

Fig. 1. The energy-passive greenhouse

The greenhouse itself is contributing to the reduction of the CO_2 atmospheric concentration by the activity of the inside plants, which is comparable to the same surface of forest [11] [12]. However the main effect of their extensive application is much more important. We consider that a sustainable solution to the global CO_2 problem is the drastic reduction of the actual agricultural surface, that is possible if we will begin to intensively use passive greenhouses. Greenhouses are much more effective than the conventional agriculture, at the same surface their production may be more than five times greater than the conventional agriculture terrains'. The surface needed for feeding the human population would such way decrease substantially, and a large scale ecological reconstruction becomes possible [13].

3. Modeling of The Passive Greenhouse

Generally speaking, alternative energy sources are expansive. In this case we have three such items. The only way that is leading towards an economic feasibility of such a structure is the dimensional optimization associated wit a smart control.

All these items have created its own market, our problem is just the correct choice of the products. Each element's nominal capacity (the constructive parameters of the greenhouse and the powers of the heat pump, wind turbine and solar panels) must be carefully balanced, taking into account the climatic features of the location, namely the air temperature, the wind's speed and the sun radiation. Besides the internal temperature which is the key factor, an optimization problem can be targeted also to the minimum investment costs. Because the passive greenhouse system is fairly complex [9], we have build a simplified model, able to assist the optimization problems and the smart automate control of the plant.

The greenhouse thermal models that we used in our previous papers were first degree input/output differential equations with time variable coefficients. This time we need to introduce as state variables the temperature amounts produced by each relevant physical effect [14]:

a) $T_\alpha(t)$ the basic inside temperature due to the environment influence, realized by the heat flow through the walls

$$\frac{dT_\alpha(t)}{dt} = k_\alpha \cdot [T_E(t) - T_I(t)] \quad (1)$$

where k_α is a coefficient of the heat flow through the walls, T_E the external temperature and T_I the cumulated inside temperature.

b) $T_F(t)$ the inside temperature amount created by ventilation:

$$\frac{dT_F(t)}{dt} = k_v \cdot F(t) \cdot [T_E(t) - T_I(t)] \quad (2)$$

where F(t) is the ventilated air flow and k_V the ventilation coefficient.

c) $T_{HP}(t)$ the temperature amount created by the heat pump:

$$\frac{dT_{HP}(t)}{dt} = k_{HP} \cdot P_{HP} \quad (3)$$

where k_{HP} is the coefficient of the heat pump and P_{HP} its nominal power.

The energy flow necessary for recirculation is given by

$$P_{REC} = \eta_{REC}(t) \cdot P_{HP} \quad (4)$$

where η_{REC} is the recirculation coefficient of the heat pump.

d) $T_W(t)$ the temperature amount created by the wind generator, in cold and windy weather, if this energy is directly heating the greenhouse:

$$\frac{dT_W(t)}{dt} = k_W \cdot V_W \quad (5)$$

with k_W the wind coefficient and V_W the wind's speed. The wind energy flow stocked in the accumulator is:

$$P_W(t) = k_{Wdim} \cdot k_W \cdot V_W \quad (6)$$

where k_{Wdim} is a dimensional factor.

e) T_{GH} the temperature amount created by the sun, mainly by the greenhouse effect:

$$\frac{dT_{GH}(t)}{dt} = (1 - \cos(\varphi)) \cdot k_{GH} \cdot L_{GH} \quad (7)$$

where k_{GH} is the greenhouse effect coefficient, L_{GH} the intensity of the sun's radiation and φ is the rotation angle of the solar panels.

The solar energy flow stocked in the accumulators is:

$$P_{SUN}(t) = k_{Sdim} \cdot \cos(\varphi) \cdot k_{GH} \cdot L_{GH} \quad (8)$$

where k_{Sdim} is the dimensional factor.

The equation of the energy stocked into the accumulator E_{AC}, is:

$$\frac{dE_{AC}(t)}{dt} = P_W(t) + P_{SUN}(t) - P_{EQ}(t) \quad (9)$$

where $P_{EQ}(t)$ is the power consumed by the electric equipment of the greenhouse.

The cumulated inside temperature is given by the equation:

$$T_I(t) = T_\alpha + T_F + T_{HP} + T_W + T_{GH} \quad (10)$$

The model is allowing us to study the passive greenhouse as a system, with the basic alternative energy sources as inputs and T_I as output.

4. The Simulink-Matlab Implementation

Given the simple mathematical model, its resulting Simulink-Matlab implementation is simple at its turn, as shown in fig. 1. Thanks to this simplicity, implementations in ASM, DSP, μP, μC, or C, become feasible. On the other hand, the model's simplicity comes together with a difficult validation, because of the complexity and the nonlinearity of the EPG system. The identification of k_α, k_V, k_{HP}, k_W and k_{GH} must be performed using real data. In this matter we are using records for several years issued of the experimental greenhouse of the LSIS Laboratory, University of Toulon-Var, France [10], [15]. In a previous work [15] we successfully used for the identification of the influence of the wind on greenhouses a two stage method:

- *Stage 1*: the identification of a "first guess" model, either by theoretical analysis, as in the case of the above presented model, or using experimental tests (step responses usually) or existing recorded data
- *Stage 2*: the optimization of the first guess model by genetic algorithms.

This way we are obtaining structural models that offer transparent knowledge about EPG, that can be used for different smart control algorithms.

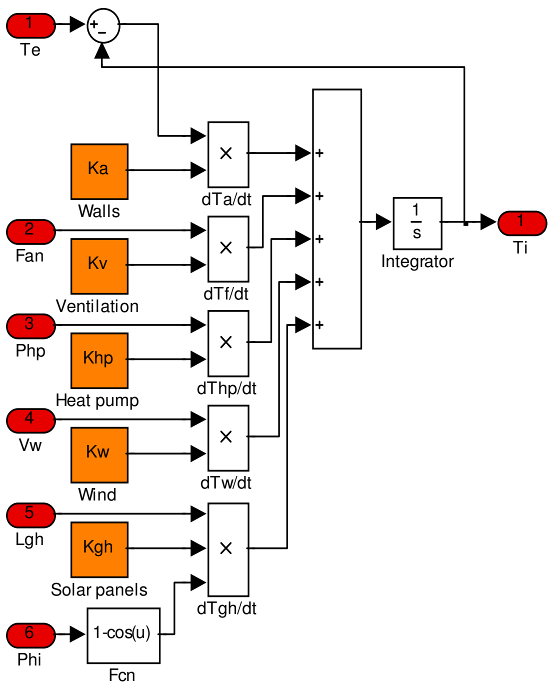

Fig. 2. The Matlab-Simulink implementation

5. Applications of the Derived Model

a) The dimensional optimization of EPG according to the local climate may be performed when statistical data about the climate are available. If we are using mean values for T_E, V_W and L_{GH}, we can compute a mean value of T_I, according to P_{HP}. Constructive links between inputs may be imposed, for example between P_{HP} and the nominal power of the wind generator [15]. Other approaches may consist in simulating different scenarios, relevant for the weather and the desired exploitation of the greenhouse, or to use experimental data - recorded weather reports.

b) The model allows the testing of different control algorithms.

c) The model may assist or be included into the EPG controller.

6. A Smart EPG Controller

The EPG's control must be based on the characteristics of the three energy sources, water, wind and sun. Heat pumps are recommended to operate in steady or slow varying regimes. The wind and the sun energies are inconstant, but since we need only to accumulate them, no particular operating constraints are needed. In these conditions sequential control algorithms are recommended. The control actions are consisting of commutations of the energy sources: turns on, turns off, connections to the accumulator, connections to the heating device, etc. We will consider the following main control actions:

- **HP→EPG**: the heat pump is warming EPG, the generic case for cold and temperate climate;
- **HP→0**: the heat pump is turned off, when the weather is warm;
- **F→EPG**: the greenhouse is ventilated;
- **F→0**: the ventilation fan is closed;
- **W→ACC**: the wind energy is accumulated;
- **W→EPG**: the wind energy is heating EPG;
- **W→0**: the wind turbine is turned off;
- **L_{GH}→ACC**: the solar panels are connected to the accumulator and shading the plants;
- **L_{GH} →0**: the solar panels are turned off;
- **ACC→EPG**: the accumulator heats EPG.

This kind of MIMO systems, highly nonlinear but with no particular accuracy constraints, may be conveniently controlled with expert systems. Our approach will rely on the fuzzy interpolative expert systems, that may be implemented by look-up tables with linear interpolations or with any other interpolative network [16], [17]. Such highly adjustable Sugeno controllers are perfectly able to cope with EPGs and allow a continuous improvement of the system, as further knowledge will be acquired. As fuzzy interpolative variables, the inputs are fuzzyfied by normalized fuzzy partitions using triangular or trapezoidal membership functions. The inference is prod-sum and the defuzzyfication is COG. The inputs used by the rule base are the following:

- εT_I the control error of T_I: *imposed*_$T_I - T_E$, with three linguistic labels: *negative*, *zero* and *positive*.
- dT the difference $T_I - T_E$ with three linguistic labels: *negative*, *zero* and *positive*.
- V_W with two linguistic labels: *weak* and *strong*.
- L_{GH} with three linguistic labels: *weak*, *medium* and *strong*.
- ACC with two linguistic labels: *charged* and *uncharged*.

The rule base's kernel contains the next rules:

1. If dT is *negative* then **HP→EPG**
2. If dT is *negative* and εT_I is *negative* then **F→0**
3. If dT is *negative* and εT_I is *positive* then **F→EPG**
4. If V_W is *strong* and ACC is *uncharged* then **W→ACC**
5. If L_{GH} is *strong* and ACC is *uncharged* then $\mathbf{L_{GH}}$ **→ACC**
6. If L_{GH} is *medium* then $\mathbf{L_{GH}}$ **→0**
7. If dT is *positive* and εT_I is *negative* and V_W is *strong* then **W→ EPG**
8. If dT is *positive* and εT_I is *positive* and ACC is *loaded* and L_{GH} is *weak* then **ACC→EPG**

The rules' linguistic description is the following:

1. When outside is cold the heat pump is turned on;
2. When outside is cold and inside is colder that desired, the natural ventilation is stopped.
3. When outside is cold and inside is too warm the ventilation is turned on.
4. When the wind is strong and the accumulator is not charged the wind turbine is charging the accumulator.
5. When the sun is strong and the accumulator is not charged the solar panels are charging it.
6. When the solar radiation is medium the panels are turned off and parallel to the sun rays, and the plants are lighted.
7. If outside is cold, as well as inside, and the wind is strong, the wind turbine is directly heating the greenhouse.
8. If outside is cold, as well as inside, and the accumulator is loaded, the accumulator is heating the greenhouse.

The rules may be changed and completed after relevant experimental tests. Elements of smart control can be added by anticipative rules, that adapt EPG to the environment conditions, avoid limit situations, save energy, etc. A promising approach is the receding horizon optimal control, applied into greenhouses field in ref. [9]. Basically, the mathematical model is used as a predictor of the greenhouses' dynamic behavior, having as input data weather forecasts. We will use the model to estimate on-line the evolution of T_I, under the influence of the actual weather parameters. This estimation is useful because the lack of a powerful and responsive heating device is significantly slowing the EPG, comparing to usual greenhouses. Although the EPG system has three energy sources, only the heat pump, that is a slow reacting device, has a significant power. The model can estimate the future evolution of EPG by a derivative input:

- $\mathbf{cT_I}$ the estimated change of the internal temperature, with three linguistic labels: *negative*, *zero* and *positive*.

The new input can help us in different ways, for instance in the nuanciation of the emergency rule no. 8, in order to avoid the discharge of the accumulator, when this is not strictly necessary. The accumulator will be connected to the emergency electric heater only if cT_I is negative:

8'. If dT is *positive* and εT_I is *positive* and ACC is *loaded* and L_{GH} is *weak* and cT_I is *negative* then **ACC→EPG**

Our preliminary simulations are showing that, although a very slow one, the EPG system is controllable by our controller. The necessary adjustments may be done at the expert system level (control rules) as well as at the fuzzyfication level (number of linguistic labels, position and shape of the membership functions).

Conclusions

The energy-passive greenhouses are able to revolutionize the agriculture, with beneficial effects of stabilizing the carbon dioxide balance in the atmosphere. Several alternative energy sources are used for these greenhouses: cold water heat pumps, wind turbines and solar panels, as well as the natural ventilation and the direct solar heating. This way the energy passive greenhouses become independent of any energetic infrastructure. We introduced a mathematical model for energy-passive greenhouses and proposed a fuzzy interpolative rule base for their control. The controller is using the model as an on-line estimator of the internal temperature's tendency. Future research will address the model identification of an experimental greenhouse and the implementation of the controller.

References

[1]. C.D. Keeling, T.P. Whorf. Atmospheric carbon dioxide record from Mauna Loa. *Carbon Dioxide Research Group, Scripps Institution of Oceanography, University of California*, http:// cdiac.ornl.gov/ trends/ co2/sio -mlo.htm.

[2]. V.V. Tuzhilkina. Carbon dioxide exchange in the photosynthetic apparatus of trees in a mature spruce phytocenosis of the northern taiga subzone. *Ekologiya*, 2006, No. 2, pp. 95–101.

[3]. B. Bellows. Solar greenhouses. *ATTRA National Sustainable Agriculture Information Service*, Fayetteville, 2003, http://www. attra.org/attra-pub/ solar-gh.html.

[4]. T. Bradford. Solar Revolution: The Economic Transformation of the Global Energy Industry. *MIT Press*. 2006.

[5]. *** Wind Turbine Design Cost and Scaling Model. *Technical Report NREL/TP-500-40566,* Dec., 2006, http://www.nrel.gov/ docs/fy07osti/ 40566.pdf

[6]. *** Ochsner Waermepumpen documentation.

[7]. C. Olivier. Ground source heat pump in France in the residential. *International Summer School on Direct Application of Geothermal Energy*, Skopje 2001. http://www. geo-thermie.de/tag-ungkongresse/vortrags-programm_igd_2001.

[8]. M.M. Balas, N. Cociuba, C. Musca. The energetic passive greenhouses. *Analele Universitatii "Aurel Vlaicu" din Arad*, 2004, pag. 524 – 529.

[9]. R.J.C. van Ooteghem. Optimal Control Design for a Solar Greenhouse. *Ph.D. thesis Wageningen University*, Holland, 2007, http://library.wur.nl/wda/dissertations/dis41 10.pdf

[10]. M.M. Balas, J. Duplaix, S. Balas. Modeling the heat flow of the greenhouses. *Proc. of IEEE International Workshop on Soft Computing Applications SOFA05*, Szeged-Hungary & Arad-Romania, 27-30 Aug., 2005, pag. 37-43.

[11]. V. Voican, V. Lacatus. Cultura in sere si solarii, *Ed. Ceres*, Bucharest, 1998.

[12]. I. Horgos. Legumicultură specială. *Ed. Agroprint*, Timisoara, 2003.

[13]. M.M. Balas, C. Musca, S. Musca. Ecological Reconstruction Using Energy-passive Greenhouses, 6th *International Conf. on Renewable Sources and Environmental Electro-Technologies*, RSEE, 8-10 June 2006, Oradea , Romania, *Computer Science And Control Systems Session.*

[14]. V.E. Balas, M.M. Balas, M. V. Putin-Racovita. Passive Greenhouses and Ecological Reconstruction, *12th IEEE International Conference on Intelligent Engineering Systems, INES 2008*, Miami, in press.

[15]. M.M. Balas, J. Duplaix, M. Bouchouicha, S.V. Balas. Structural modeling of the wind's influence over the heat flow of the greenhouses, *Journal of Intelligent &Fuzzy Systems*, Vol. 19, Nr. 1, 2008, pp. 29-40.

[16]. M. Balas, V. Balas. The Family of Self Adaptive Interpolative Controllers. *Proc. of Information Processing and Management of Uncertainty in Knowledge-Based Systems (IPMU'04)*, Perugia, July, 2004.

[17]. L.T. Kóczy, M. Balas, M. Ciugudean, V.E. Balas, J. Botzheim. On the Interpolative Side of the Fuzzy Sets. *Proc. of IEEE Sofa'05*, Szeged-Arad, Aug. 2005, pp. 17-23.