PEAK LOAD REDUCTION BY USING HEATING REGULATORS

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ABSTRACT

This paper presents a development of a heating regulator that allows to reduce the peak consumption while maintaining thermal comfort.

The proposed temperature regulator is tested by simulation with satisfactory results for a house containing seven radiators. Other loads such as freezer, refrigerator, cooker, washing-machine ... are taken into account.

The proposed solution can be applied for a group of loads or buildings (such as a virtual consumer) in order to reduce the peak consumption in the distribution network. An application in order to avoid congestion in the distribution network is presented.

INTRODUCTION

The sector of the building (residential and tertiary) in France in 2005, with 43% of the final energy demand and 64% of the electric demand [1], presents one of the greatest potentials of energy efficiency and reduction of the gas emissions. The use of the loads in an active and intelligent way and with an optimal load management are one of the major concerns of the managers, the providers and the consumers of energy.

The reduction of the peak consumption is one of the most effective solutions of energy management systems. This reduction brings many interests such as:

- For the customers: to reduce the bill for the subscription and consumption in rush hours
- For the DNO: to avoid the congestion and the technical problems caused by overloads
- For the energy provider: limit the purchase of an expensive energy.

The heating is a controllable load and takes an important part in the tertiary and residential buildings (75% for the residential sector, 30% for the tertiary sector) [2].

Therefore the management of heating has an important potential to reduce the peaks of consumption and permits to contribute to service system in distribution.

PRINCIPLE OF THE PROPOSED TEMPERATURE REGULATOR

In general, a modern radiator is equipped a temperature regulator (called classical regulator). This regulator is used to maintain the temperature in a specified value. In order to reduce the peak consumption for energy management system, this part presents a development of a temperature regulator for radiators.

In the normal operation (without stepping beyond of contractual demand or without an outdoor signal from DNO-Distribution Network Operators or energy provider), the regulator operates like a normal temperature regulator in order to ensure thermal comfort (Ex: $T_{setpoint}$ ±1 where $T_{setpoint}$ is constant and fixed). In case of stepping beyond of contractual demand or with outdoor signal (ex: congestion signal generated by DNO), the regulator switches to mode of adaptive regulator with a variable set-point value of temperature in order to limit the peak of consumption to a predefined level. At the time in which with the consumption is too important (too many radiators operate at the same time), the radiators that have the lowest temperature are in priority. The priority between the radiators is managed by comparing the variations of temperature of the room (instantaneous, measured by the radiator) with the corresponding set-point value. With this developed temperature regulator, the thermal comfort is maintained. The algorithm of the proposed heating regulator is represented in Fig.1.

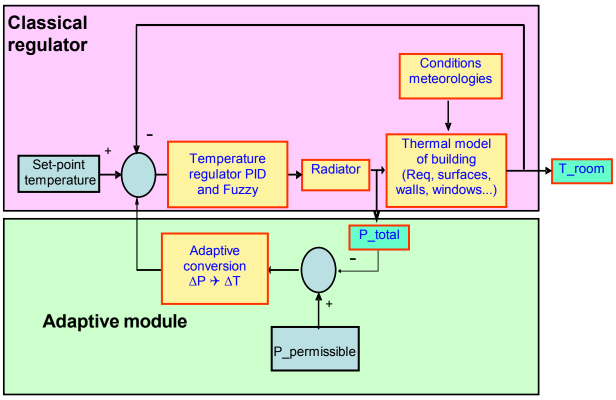

Fig.1: Algorithm of the heating regulator

For reason of simplicity, we suppose that there are only two radiators. Fig. 2 and Fig. 3 show the principle that allows to limit the peak of consumption when there is a waning signal of the stepping beyond of the contractual power.

By using a classical regulation (Ro in Fig. 8), the maximum power is:

$$Pmax = P1+ P2 >> P\_perm$$

Where P1, P2 is power of the radiators 1 and 2, and P_perm is permissible power (ex: contractual power).

By using the proposed regulation (R1 in Fig. 9), with the help of variable T_max, which is the function of the exceeded power, the power becomes:

$$P\_max = P1= P2 << P\_perm$$

The thermal comfort is maintained because T_min is not varied.

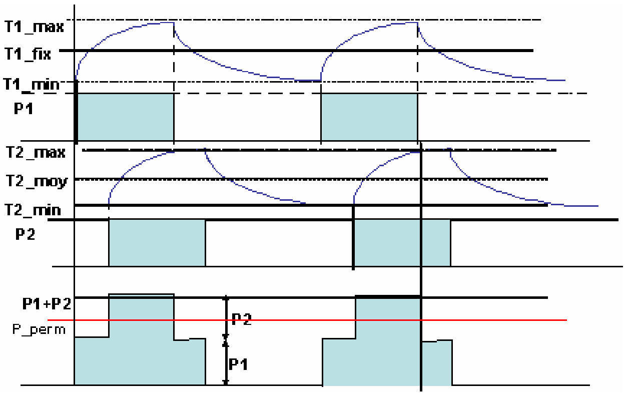

Fig.2: Operation of a classical heating regulation (Ro).

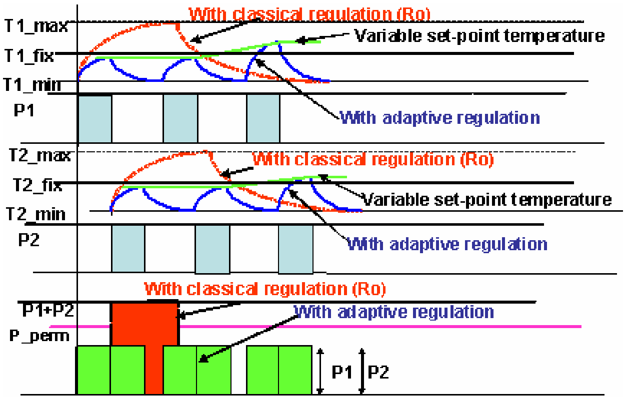

Fig.3: Operation of a developed heating regulation (R1).

APPLICATION CASE FOR A HOUSE

The proposed temperature regulator is used for simulation of a house containing 7 radiators. Other loads such as freezer, refrigerator, cooker, washing- machine… are taken into account.

This house includes the following electrical appliances:

6 radiators x 1500 W = 9000 W (for Bedrooms N°1, 2, 3, 4, Kitchen and Bathroom)

1 radiator	2000 W (for Living-room)
1 electric cooker	2500 W
1 electric cooker	1500 W
1 refrigerator	150 W
1 freezer	125 W
1 dishwasher	1600 W
1 washing-machine	2400 W

Total power = 19275 W = 19.275 kW

Set-point temperature of all rooms: 20°C.

The room is considered as a system closed. In this case, we do not take into account of the thermal transfer by radiation and convection. I.e. we consider thermal losses just by the heat exchanged with external air by surfaces of the envelope of building such as walls, doors and windows and internal profits of energy due to the equipment, the lights and people.

Applying the energy conservation equation for each element, the dynamic model for the room, which includes the electric radiators can be written as [3]:

$$\rho_c c_o V_c \frac{dT_{\text{int}}}{dt} = Q + q_1 + q_2 ... + \frac{1}{R_{eq}}(T_{ext} - T_{\text{int}}) \quad (1)$$

- ρ_C = Density of air (1.225 kg/m^3)
- c_o = Specific heat of air (1005.4 J/kg-K)
- Vc = Volume of room (m^3)
- Q = Heat produced by the radiators (J/s)
- q_1, q_2… = Heats produced by lamp, computer, nobody….
- R_{eq} = Equivalent thermal resistance of room (depend on the walls, windows, doors)
- Text = Exterior temperature
- Tint = interior temperature.

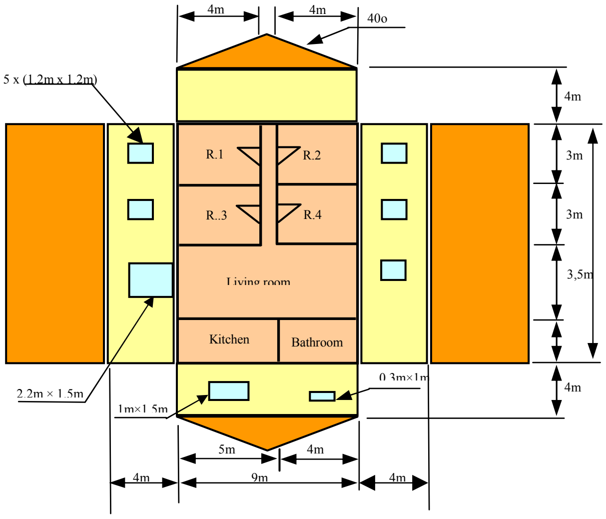

Fig.4: Plan of the house used for simulation

Thermal resistance of window and door:

$$R_{win\_door} = \frac{L_{win\_door}}{k_{win\_door} A_{win\_door}} \quad (2)$$

Thermal resistance of the wall:

$$R_{wall} = \frac{L_{wall}}{k_{wall} A_{wall}} \quad (3)$$

Equivalent thermal resistance of the room:

$$R_{eq} = \frac{R_{wall} R_{win\_door}}{R_{wall} + R_{win\_door}} \quad (4)$$

In approximate calculation, we consider the heat produced by lamp, computer, nobody q_1, q_2… is equal to zero, therefore Eq. (1) becomes:

$$\frac{M}{c_o} \frac{dT_{\text{int}}}{dt} = Q + \frac{1}{R_{eq}}(T_{ext} - T_{\text{int}}) \quad (5)$$

- M = ρ_c x V_c: Mass of the air of the room
- V_c : Volume of the room
- Q : Heat produced by the radiator

The thermal model of the room is thus represented in Fig.5. The modular model scheme of the house with all appliances simulated by Simulink is presented in Fig. 6.

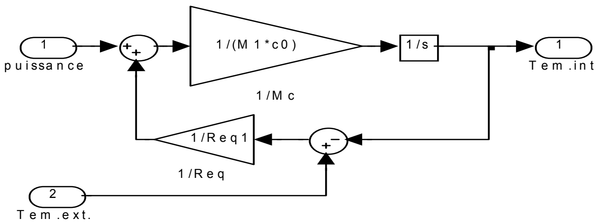

Fig.5: Thermal model of one room by Simulink

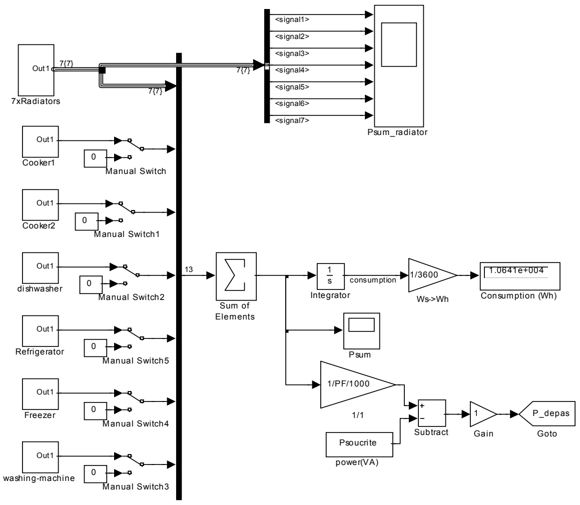

Fig.6: Modular model scheme of the house by Simulink

Fig.7 shows the operation of the washing-machine within 24 hours. In the same way, the operation of the other loads in this house such as the refrigerator, freezer, dishwasher and cooker 1, 2 is reproduced from our measurements for the different types of load in building.

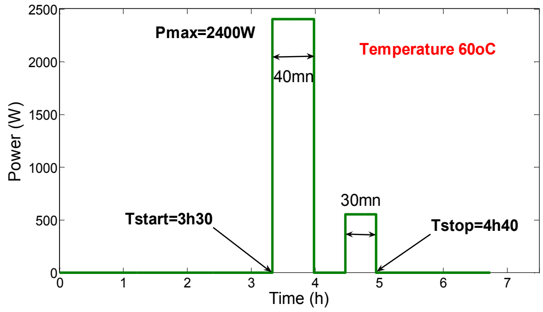

Fig.7: Operation of the washing machine

Results of the simulation

The analysis of this house is done by MATLAB/Simulink when the set-point temperature of room air temperature is equal to 20°C and the exterior temperature varies as a sinus function with the different mean temperatures (5, 0, -10°C) and a thermal amplitude of 5°C. Simulation is effected for 24 hours (from 0h to 24h=86400s).

Figs. 8-9 show the total power of the house and Figs 10, 11 show interior temperature of the bedroom N°1 when the mean exterior temperatures is -10°C (with Ro and R1).

The results (the maximum total power P_{max}, energy consumption, contractual power P_con) that correspond to two cases, with Ro and R1, are presented in table 1.

These results indicate that:

- The proposed heating regulator allows to reduce the contractual power to 9kVA instead of 12 or 15 kVA
- Thermal comfort is maintained because the interior temperature of the rooms is always maintained between 21°C and 19°C. Fig. 11 shows the maximal temperature is variable and the minimal temperature is always maintained at 19°C
- Energy consumption is almost identical between two cases (with Ro and with R1).

It shows that with a reduction of contractual power, the total cost of subscription is reduced.

Table 1: Pmax and P_con for different scenarios

Text-mean (°C)	Pmax (kW)	Consumption (kWh)	P_con (kVA)	Heating regulation
5	10.175	44.119	12	Ro
5	8,125	44.113	9	R1
0	11.675	56.750	15	Ro
0	8.125	56.720	9	R1
-10	11.275	82.046	15	Ro
-10	8.400	81.971	9	R1

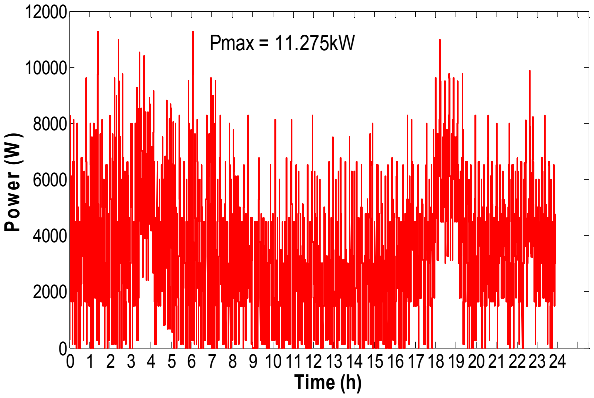

Fig.8: Total power with Ro

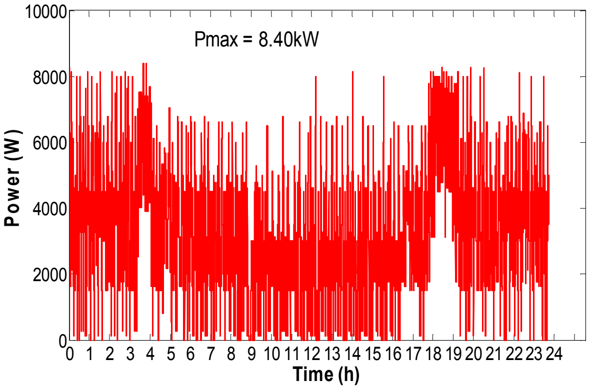

Fig.9: Total power with R1

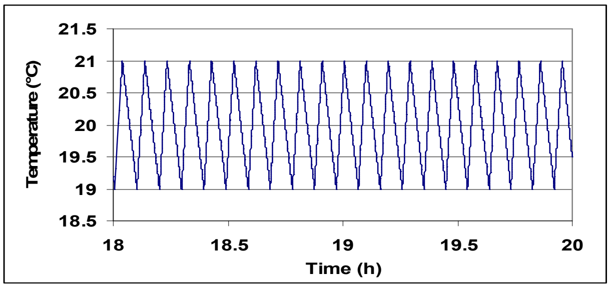

Fig.10: Interior temperature of bedroom N°1 – with Ro

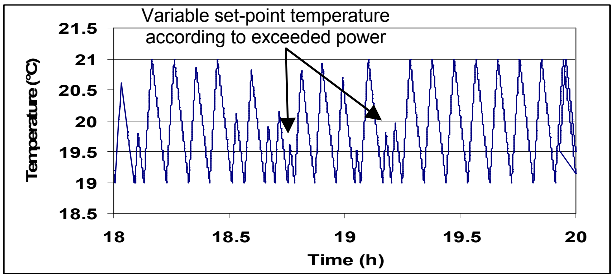

Fig11: Interior temperature of bedroom N°1 – with R1

In order to show influence of outdoor signal generated by DNO on the operation of regulation, other scenario is presented here. When the mean exterior temperature is 0°C while the permissible power is changed (100%, 95%, 90%, and 85% from the initial power: 9kVA) according to outdoor signal from DNO-Distribution Network Operators or energy provider. The results of the simulation that are presented in table 2 indicate:

- All demands of DNO or energy provider are satisfied
- The thermal comfort is maintained because the minimum interior temperature of the rooms are always maintained at Tmin = T_setpoint -1 = 19°C
- The differences of the energy consumption are negligible between the cases
- In a special case, when the permissible power becomes too small the thermal comfort is not maintained.

Table 2 Maximal power for different scenarios

Tmin_room (°C)	P_permissible (kVA)	Pmax (kW)	Consumption (kWh)
19	P_con = 9kVA	8.125	56.720
19	0.95xP_con = 8.55kVA	8.275	56.686
19	0.9xP_con = 8.10kVA	7.775	56.686
19	0.85xP_con = 7.65kVA	7.500	56.721

In order to show the performance of proposed method, a rural network is used (Fig. 12). Without load management a congestion appears between 18 and 21H on 160kVA transformer (overload about 10% in Fig. 13). By using the proposed method, after receiving a signal in outdoor, the maximal permissible power for all customers containing radiators is decreased by 10%. After this action, the congestion is eliminated and thermal comfort is assured.

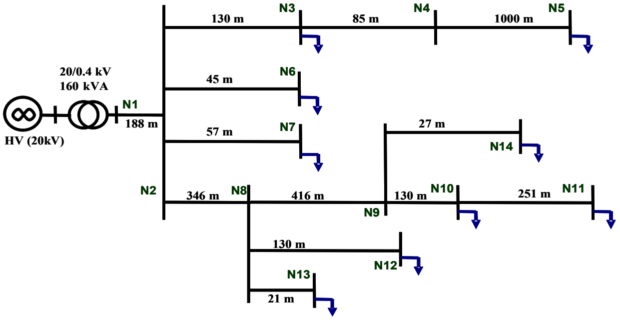

Fig. 12: LV rural network used to study

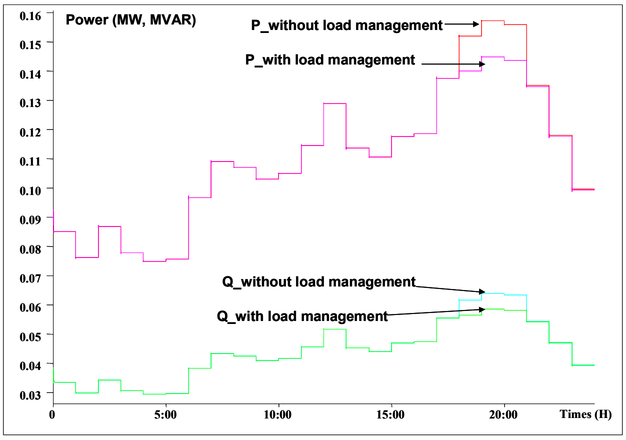

Fig. 13: Power of transformer in case with and without load management

CONCLUSIONS

The results of simulation show that the proposed thermal regulator permits to reduce efficiently the peak consumption while maintaining thermal comfort. This method can adapt to the conditions to a new context (by taking into account of the dynamic tariffs, of the signals of the provider or the manager of the network). By using the proposed regulator, it is an intelligent solution of load management.

The proposed solution is applied to a group of loads or buildings (such as a virtual consumer) in order to reduce the peak consumption in the distribution network. An application in order to avoid congestion in a rural distribution network is presented.

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[3] Nathan Mendes, Gustavo H.C. Oliveira and Humberto X. de Araújo, 2001, "Building thermal performance analysis by using Matlab/Simulink", Seventh International IBPSA Conference