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Air Conditioner Direct Load Control in Distribution Networks

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Abstract – In order to use loads in an active and intelligent way to resolve technical problems in the networks or contribute to ancillary services, this paper presents a development of air-conditioning control that allows to reduce the peak consumption by maintaining thermal comforts. This control is based on the variable set-point temperature of air conditioning adapted to the permissible power. This power can be fixed by outdoor signal from DNO (Distribution Network Operators).

The proposed air-conditioning control is tested by simulation under EMTP-RV with satisfied results for a distribution network containing air-conditioners. Different factors such as: weather conditions, the thermal parameters of buildings and other residential loads (lightning, freezer, refrigerator, cooker, washing-machine …) are taken into account.

These results show that the proposed solution can be efficiently applied for a group of loads, buildings (such as a virtual consumer) in distribution networks in order to reduce the peak consumption in the distribution network.

***Index Terms*— Air conditioning, direct load control, adaptive control, peak load reduction, distribution network.**

I. Introduction

Load management is defined as sets of objectives designed to control and modify the patterns of demands of various consumers of a power utility. Load management permits to limit or shift peak load from on-peak to off-peak time periods. Load management is dedicated to control systems which monitor and plan the energy demand of a building or larger zone. They can be programmed to control lighting, thermal comfort equipment, HVAC (Heating, Ventilating, Air Conditioning), refrigeration equipment, pumps, valves and motors (Fig. 1).

The sector of the building 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 optimal load management is one of the major concerns of the managers, the providers and the consumers of energy.

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

- For the customers: reduce the bill for the subscription and consumption in rush hours,
- For the DNO (Distribution Network Operator): avoid the congestion and the problems caused by overloads,
- For the energy provider: limit the purchase of an expensive energy.

In order to develop the intelligent electric distribution networks in the future (intelligent grid), direct load control for controllable loads plays an important role. Loads become active and intelligent. The loads participate to resolve technical problems in the networks or contribute to ancillary services such as voltage control, congestion management…

The air-conditioning is a controllable load. For tropical countries in summer, it takes an important part in the tertiary and residential buildings. Demand Side Management (DSM) considers air-conditioning load as one of the most suitable loads to implement direct customer load control in order to exercise peak demand control as well as energy consumption control in supply systems [1-8]. In DSM, the air-conditioning units located at customer premises are directed to enter energy/demand saving control modes by means of control signals issued by DNO from sub stations either via remote radio link or via power line carrier communication link at distribution level when the utility wants to exercise demand control during periods of power shortage. Therefore the management of air conditioners has an important potential to reduce the peaks of consumption and permits to contribute to ancillary services in distribution.

In this paper, an adaptive control of air-conditioning units is proposed. Then the proposed solution is applied for a distribution network in order to reduce the peak load consumption and to avoid congestion.

II. Principle of The Adaptive Control of Air-Conditioner

A. *Model of air conditioner*

The operation of an air conditioner is based on the phase change of a fluid refrigerant: evaporation occurs with heat absorption, condensation with heat production.

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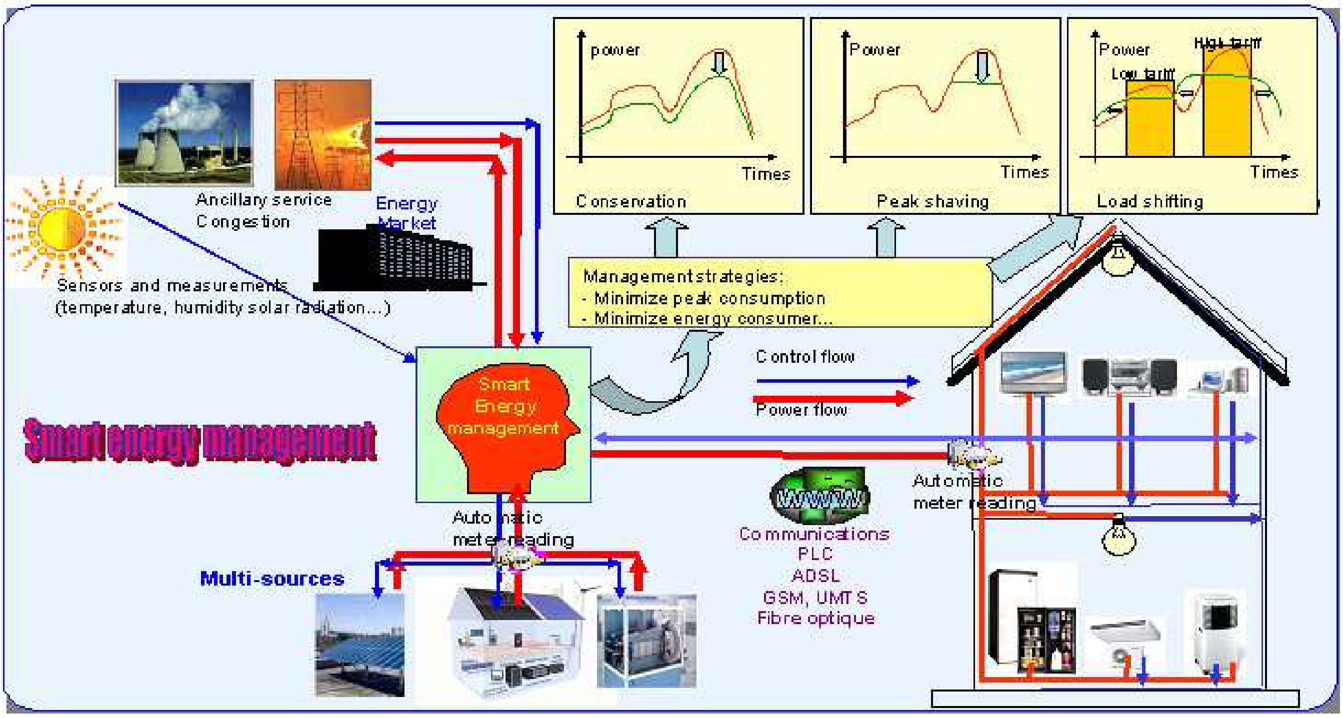

Fig. 1. Energy and load management system

Therefore, in any air conditioner there is:

- An exchanger evaporator where cooling associated with the evaporation of refrigerant is transmitted to the ambient air;
- A compressor compressing the gaseous fluids, increasing pressure and temperature;
- An exchanger condenser where gas transfers its heat by condensing;
- A relief valve decreasing the pressure of the liquid refrigerant before its evaporation in the heat exchanger.

It will take into account the sensitive loads and loads latent:

1) The sensible load (heat gain) :

- Heat flow from warmer surroundings
- Heat flow from solar radiation
- Heat flow into the space from energy consuming objects within the space; these objects usually include: lamp, computer, the body…

2) The latent load (water vapor gain):

- Moisture entering the space from surroundings.
- Moisture generated within the space from moisture generating objects. These objects usually include: occupants cooking, warming appliances industrial or production machinery which evaporates water.

In this paper, the electrical analogue model for an air conditioned house proposed in [7] is used (Fig. 2). Fig. 3 shows the model of an air conditioning developed with EMTP-RV. From this model, we propose a new method based on the adaptive control of air-conditioner for load management system.

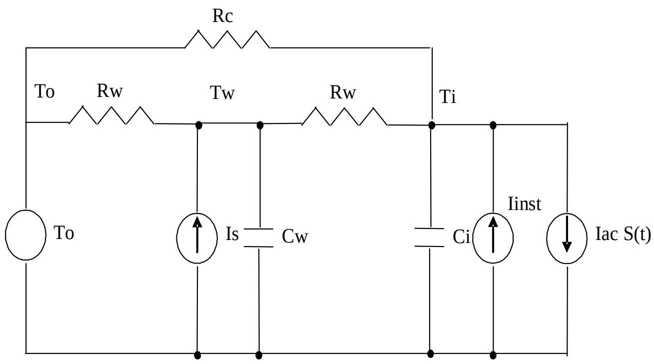

Fig. 2. Electrical analogue model for an air conditioned house

Where:

- Rw, Cw: the equivalent thermal conduction resistance and thermal storage capacity of the house (wall, base, roof)
- Rc, Ci: the equivalent thermal conduction resistance of the average air infiltration and thermal capacity of the air inside the house
- To, Tw, Ti: the exterior temperature, the wall temperature and interior temperature
- Is : the current source of two components (solar irradiation and the portion of internal heat sources involved in this indirect heating of air)
- Iinst: the current source of heat source produced by lamp, computer, the body…
- Iac: The heat removed by the air conditioner
- S(t): The switching function (= 1 when the compressor motor is ON and = 0 when the compressor motor is OFF).

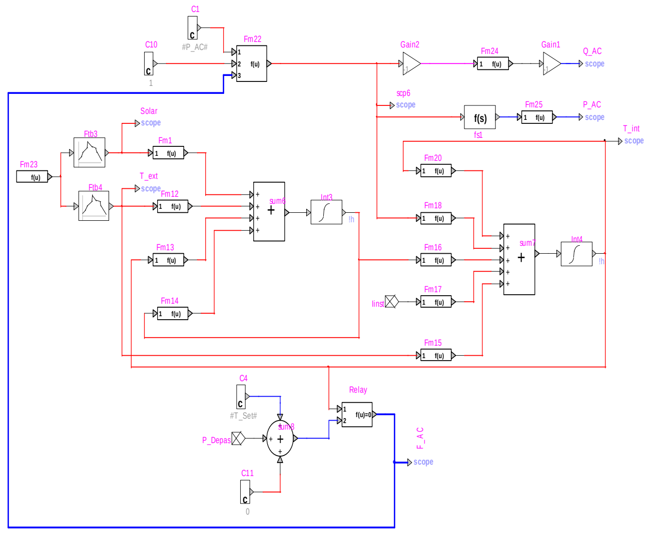

Fig. 3. Air conditioner modelized using EMTP-RV

In Fig. 2, the equivalent thermal conduction resistance of inside-wall and outside-wall (Rw) are assumed to be equal.

The differential equation system is obtained by applying Kirchoff'law at the nodes:

$$\frac{dTw}{dt} = \frac{Is}{Cw} + \frac{Ti}{RwCw} + \frac{To}{RwCw} - \frac{2Tw}{RwCw} \qquad (1)$$

$$\frac{dTi}{dt} = \frac{Iinst}{Ci} - \frac{IacS(t)}{Ci} + \frac{To}{RcCi} + \frac{Tw}{RwCi} - \frac{Ti}{Ci}\left(\frac{1}{Rw} + \frac{1}{Rc}\right) \qquad (2)$$

Where Tw and Ti are the unknown variables.

The Fig. 3 shows the EMTP-RV model of the air conditioner that is built from this differential equation system.

In order to connect to distribution network, the air conditioner is modeled with EMTP-RV by a current injection.

B. Proposed adaptive control

In general, a modern air conditioner is equipped with a temperature regulator (called classical control). This regulator is used to maintain the temperature in a specified value and carried out by a thermostat (a bimetal or an electronic thermostat). The classical controls can ensure the thermal comfort, but this method is not able to vary the power consumption and can also cause an excess from a permissible power fixed by outdoor signal from DNO (Distribution Network Operators).

In order to reduce the peak consumption for a network in presence of air conditioners, this part presents a development of an adaptive temperature control for air conditioning.

In the normal operation (without excess of contractual demand or without outdoor signal from DNO or energy provider), the regulator operates like a normal temperature regulator to ensure thermal comfort (Ex: $T_{set\text{-}point}$ ±1 where $T_{set\text{-}point}$ is constant and fixed).

In case of excess of contractual demand or with outdoor signal (ex: congestion signal generated by DNO), the regulator switches to the adaptive regulator mode with a variable set-point value of temperature in order to limit the peak of consumption to a predefined level. The principle of the proposed air conditioning regulator is represented in Fig.4.

In case of excess of contractual demand or with outdoor signal, this signal converts it into a temperature variation corresponding to required reduction power. This value is transmitted to each air conditioning in order to modify the set-point temperature.

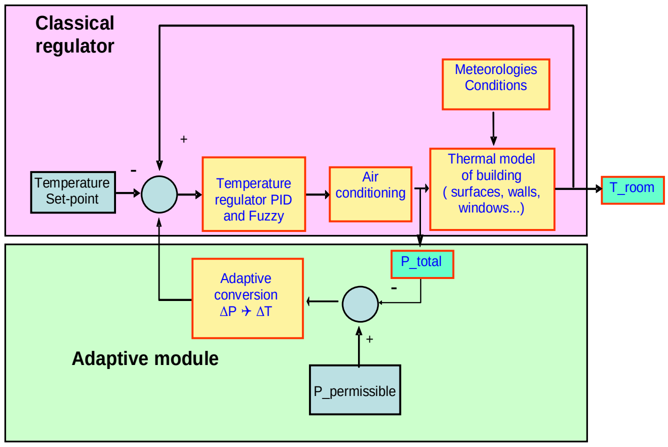

Fig. 4. Principle of the proposed air conditioning control

In a distribution network with different houses, the permissible power signal of DNO is generated from sub stations.

III. Application For A Distribution Network

The proposed temperature control is used for air conditioner load in a LV rural distribution network as shown in Fig. 5. This network is connected with a MV network via a 100 kVA, 20/0.4 kV transformer. This network contains 12 air conditioners with 5kW for individual houses. Other loads (lightning, freezer, refrigerator, cooker, washing-machine…) are considered as an equivalent load in each house. Fig. 6 shows the daily variation of these loads (active and reactive power). The maximal active power is 5 kW. The power factor of equivalent load is 0.93. The total consumption of each house includes two parts: consumption by air-conditioner and consumption by this equivalent load.

The exterior temperature variation is presented in Fig. 7. Total equivalent power obtained from solar irradiation (Is) for each house is showed by (Fig. 8). We suppose that the load variation, the exterior temperature variation and the solar irradiation are identical for all houses in this network.

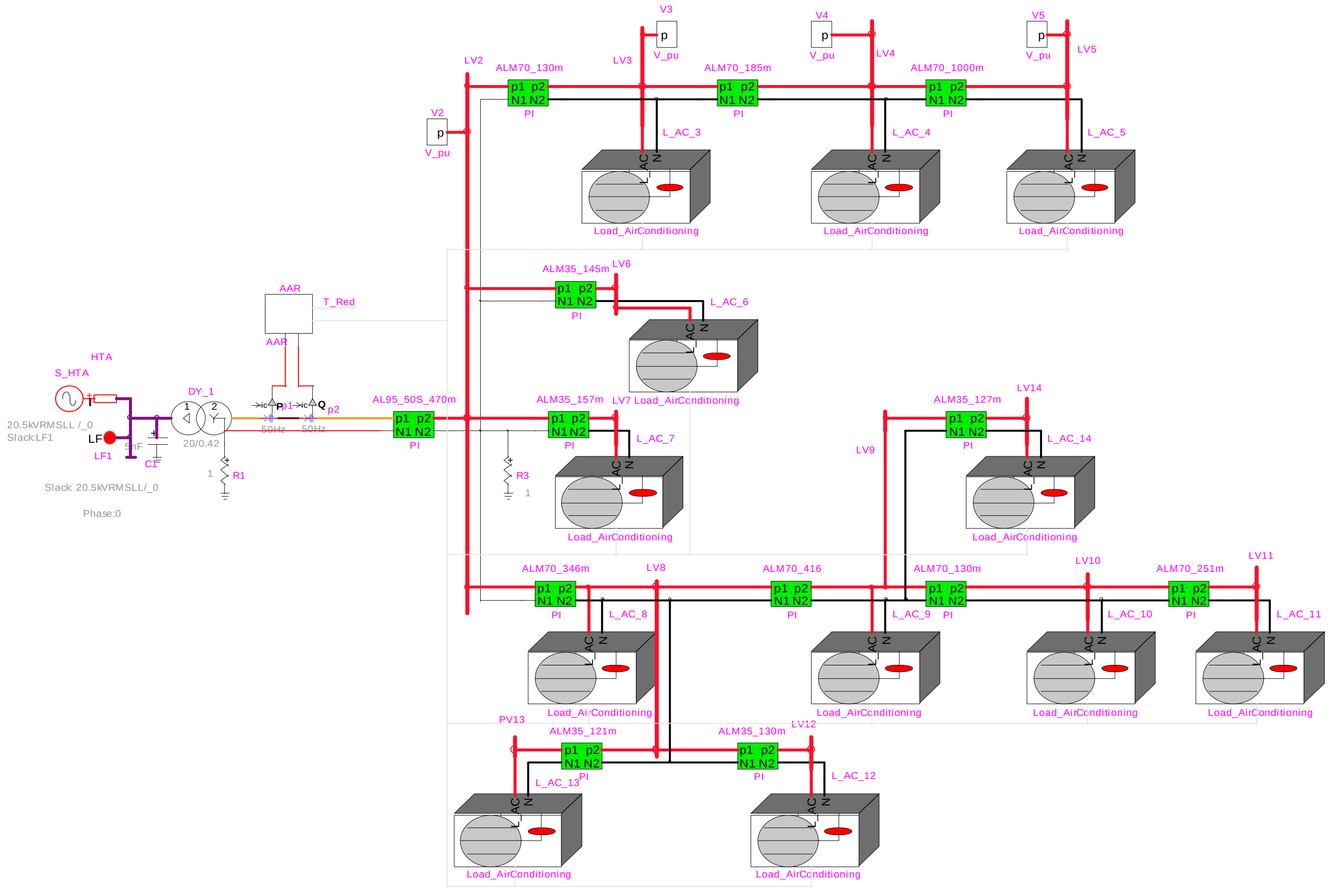

Fig. 5: Rural distribution network with air conditioners simulated with EMTP-RV

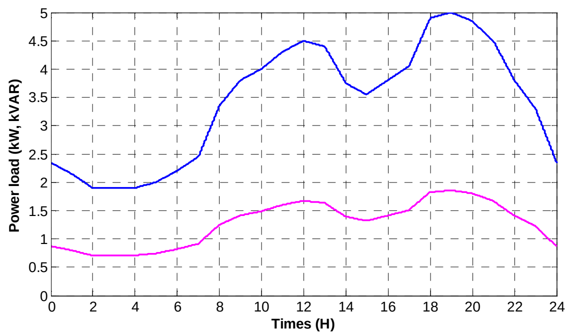

Fig. 6. Daily variation of residential loads in each house without air conditioners

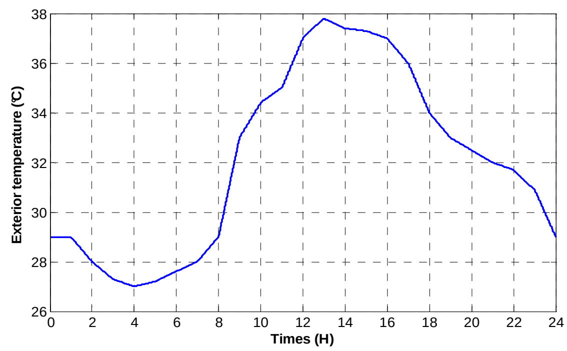

Fig. 7. Exterior temperature

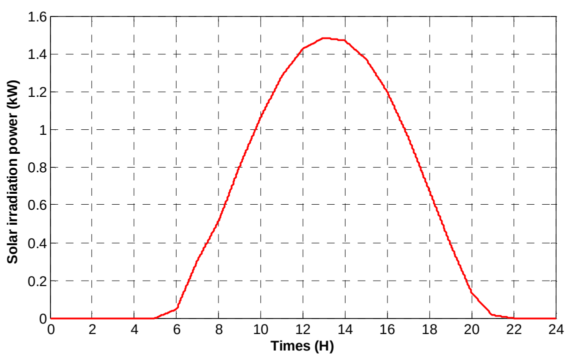

Fig. 8. Total power obtained by solar irradiation for each house

A. Classical temperature control

For this case, the set-point temperature of each house is 20°C (±1°C) and all the air-conditioners use the classical temperature control. The permissible power is fixed to 100 kVA. This is the rated power of the HV/LV transformer.

Fig. 9 shows the total power measured at the transformer. It shows that there is a 10% overload between 17 and 21H. The power of air-conditioner and the interior temperature of the house at bus 4 are presented in Figs. 10 and 11.

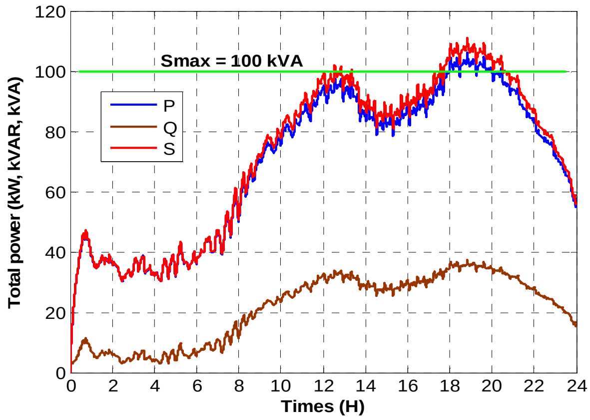

Fig. 9: Total power (with classical control) of the network

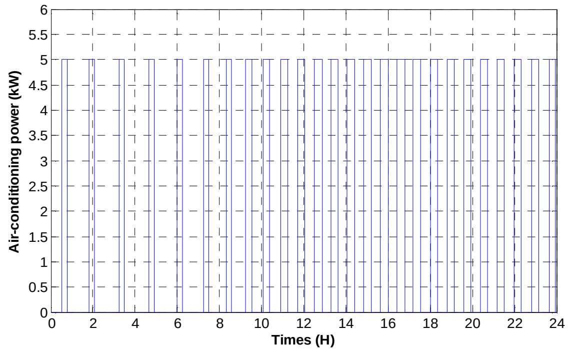

Fig. 10. Power of air-conditioner of the house at bus 4 (with classical control)

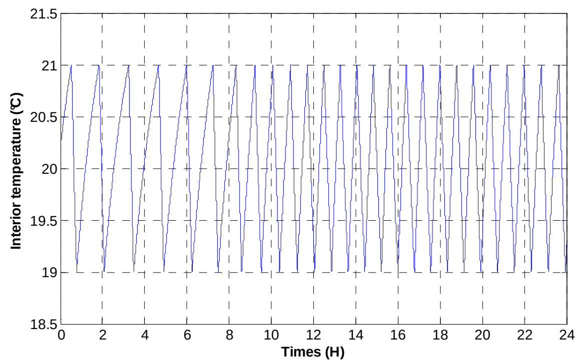

Fig. 11. Interior temperature of the house at bus 4 (with classical control)

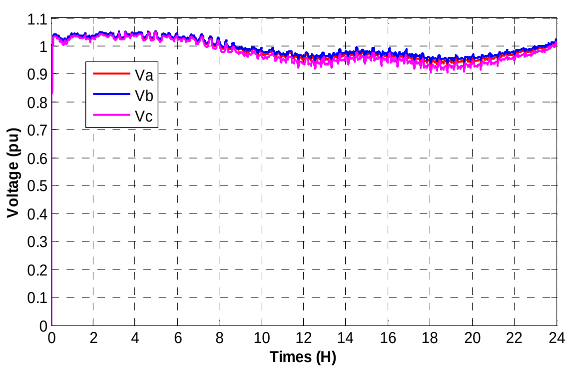

Fig. 12. Three phase voltage at bus 4 (with classical control)

It shows that the interior temperature is maintained at 20°C (±1°C). The thermal comfort is assured for all houses.

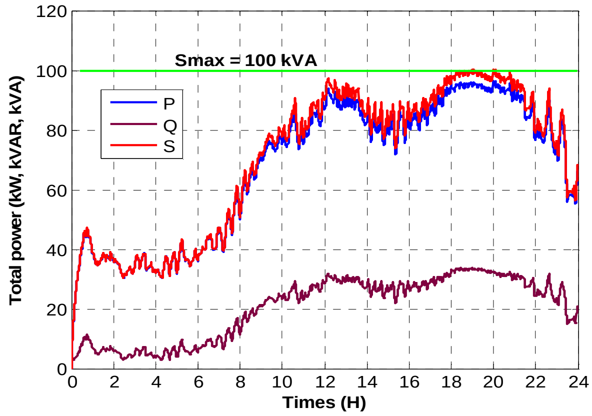

Fig. 13. Total power without load control of the network

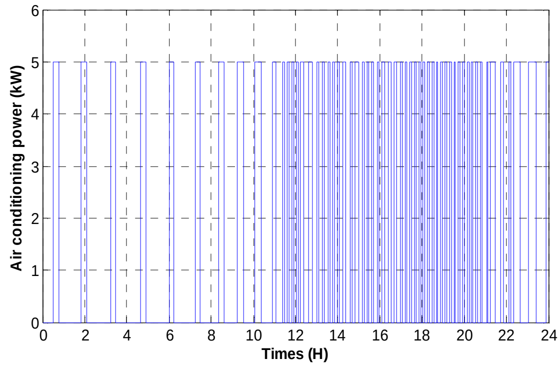

Fig. 14. Power of air-conditioner of the house at bus 4 (with adaptive control)

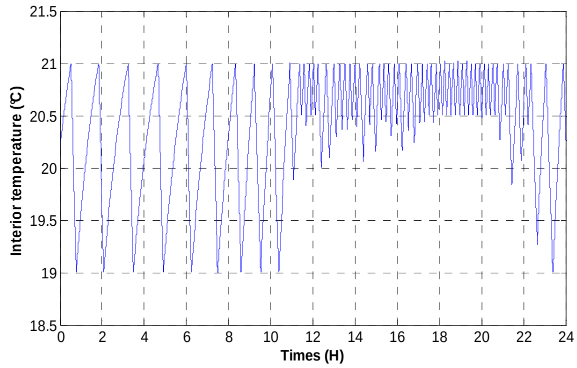

Fig. 15. Interior temperature of the house at bus 4 (with adaptive control)

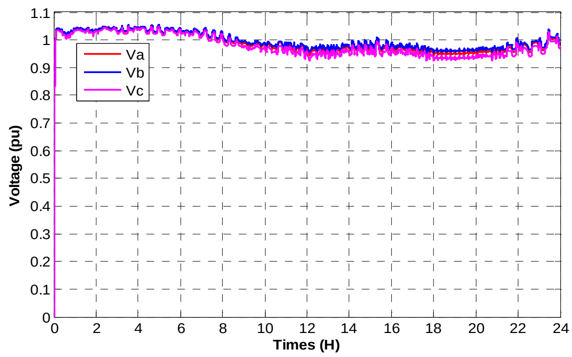

Fig. 16: Three phase voltage at bus 4 (with adaptive control)

Fig. 12 shows the three phase voltage variation at bus 4. In light load (0-6H) the voltage is high, and in heavy load (10-

22H) the voltage is low. The voltage is always maintained between 0.9 and 1.1 pu.

B. Proposed method

In this case, the adaptive control is applied for all air-conditioners in this network. The set-point temperature of each house is 20°C (±1°C).

Fig. 13 shows the total consumption power of the network. The maximal power is always inferior to 100 kV. With the help of the proposed method, the overload in transformer is avoided. Fig. 14 presents the operation of the air-conditioner at bus 4. The thermal comfort is maintained in this case (Fig. 15), because the maximal interior temperature is always inferior to 21°C for all houses. Fig. 16 shows the three phase voltage variation at bus 4. It shows that the voltage in heavy load is improved in comparison with the classical control case. This method can be applied to voltage control.

With the help of this method, the thermal comfort is assured if the permissible power is reduced to 90 kVA (-10%) and the set-point temperature ($T_{setpoint}$) is 21°C. When the permissible power is lower than 0.9Smax (90kVA) the thermal comfort is broken. It means that with a peak load reduction to avoid congestion superior to 10%, the comfort is not maintained with $T_{setpoint}$=21°C (±1°C). If the permissible power, fixed by DNO, is 0.8 Smax (80 kVA), the maximal temperature is increased to 23.5°C. This is equivalent to a 20% load shedding.

IV. Conclusion

The results of simulation show that the proposed method permits to reduce efficiently the peak consumption while maintaining thermal comfort. The suggested method can be applied for the various types of loads (ex: heating) and adapted to the context in the future by taking into account the economic and technical signals from manager and DNO (ex: congestion, dynamic tariff…). The obtained results show that this method can be applied to contribute to ancillary services such as voltage control in distribution networks.

The proposed solution is applied to a group of loads or buildings (such as a virtual consumer) in order to reduce the peak consumption (or congestion management) in a large distribution network. In order to reduce peak consumption, this method avoids a violent load shedding. This control only modifies adaptively the set-point value of temperature for each air conditioner to obtain a desired (permissible) power, fixed by DNO. On the one hand, this method avoids a hard optimal calculation with a slow response. On the other hand, this solution avoids a load prevision that is sometimes not accurate and very complicated.

V. Biographies

Tuan TRAN-QUOC (M' 93, SM' 99) received his Ph.D. degree in Electrical Engineering and "*Habilitation à Diriger des Recherches*" degree from the Grenoble - Institut National Polytechnique (Grenoble-INP) in 1993 and 2000, respectively. He works with IDEA as a Project Manager. His research interests are in the fields of power system analysis, operations, electromagnetic transients and load management.

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Nouredine HADJSAID received his Ph.D. degree in Electrical Engineering and "Habilitation à Diriger des Recherches" degree from the Institut National Polytechnique de Grenoble (INPG) in 1992 and 1998, respectively. From 1988 to 1993, he served as a research and teaching assistant at the Ecole Nationale Supérieure d'Ingénieurs Electriciens de Grenoble (ENSIEG) and at the Laboratory de Genie Electrique de Grenoble (G2Elab). He is a professor at Grenoble-INP.

C**hristophe KIENY** was born in 1956. He graduated from Ecole Polytechnique (X77) and received his ingenieur diplome degree from the Ecole Supérieure d'Electricité in 1982. He has been with Electricité de France-Direction des Etudes et Recherches - since that date. He is now, deputy director of IDEA.

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