LOAD CONTROL TO BALANCE LIMITED OR INTERMITTENT PRODUCTION

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ABSTRACT

Since the beginning of the 90's, most European countries have seen an increasing growth of Dispersed Generation (DG) on their power systems, due to several factors including government incentives, deregulation of energy market, and environmental requirements. In this context, this paper will investigate consumers' opportunities to help to ensure Production/Consumption balance, by subscribing to Load Management programs. Obviously, such action will depend on the dynamics and duration of the control, but also on load characteristics. After introducing load classification, models are presented. Two kinds of adaptive load consumption algorithms are explained and illustrated on study cases, showing how load control can help to balance intermittent production.

INTRODUCTION

Distribution networks are nowadays currently facing new challenges with the introduction of dispersed generation (DG), and the deregulation of the electricity market. This paper investigates how load control will help to ensure Production/Consumption balance in the future through local actions, especially for limited or intermittent production. With an increasing growth of DG on distribution network, and taking into account the decentralisation, some services will certainly appear such as local Production/Consumption balance. Obviously, this contribution will only be possible with the large scale diffusion of New Information and Communication Technologies (NICT) which are currently in expansion. Development of Load Management algorithms requires load classification and models; this paper will first present a classification of loads, and an inventory of models. Next, two kinds of algorithms for adaptive consumption are detailed, and illustrated on study cases.

LOAD CLASSIFICATION AND MODELS

Load classification

A large diversity of loads is distributed on the network. In order to implement efficient load control strategies, a classification is required to determine which loads are the most appropriate for a specific load control. This classification is multi-criteria: it depends on various parameters, such as controllability, power, use, controllable power and time margin, load type, and dynamics [1]. It also depends on the field of application (residential, commercial, industrial or agricultural), and on the scale of the pool of loads (a single house, a neighbourhood, a facility, a town…).

Loads that cannot be controlled are defined as **critical**, even if this term could be misunderstood. Depending on their characteristics, **controllable loads** can be used in different ways. Some loads are called "controllable" because they can be interrupted fully or partially for a determined or undetermined duration. Other loads are "pre" or "post-shiftable", because they can be advanced or delayed without significant drawback for users.

Simultaneously, a control level is defined for each load, depending on these notions. Figure 1 presents an example of this classification, according to their controllability [1].

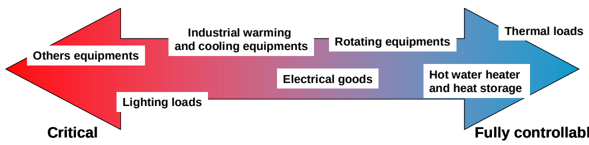

Figure 1: scale of controllable loads

Thermal loads: These loads are composed of heating, ventilating and air conditioning equipment. Thermal comfort equipment represents between 30% and 50% of energy consumption of residential and tertiary sector buildings [2]. The thermal inertia of these loads can be utilized in load control strategies, without degrading users' comfort.

Hot water heater and heat storage: Electrical hot water heaters are easily controllable. Demand Side Management (DSM) programs in the USA take benefit of these loads. Integration of NICT would enable a better tune of these loads to electricity market, and to network constraints [1].

Rotating equipment: These loads are composed of ventilation and pool pumps. Such a kind of load control program exists in California [3].

Electrical goods: These loads are mainly composed of dryers and washers. They present the opportunity to be shifted. DSM programs in the USA largely use these applications so as to smooth consumption peaks. Moreover electrical goods constructors try to improve these equipments behaviour in order to be more efficient in concern of the load control [4].

Industrial warming and cooling loads: These loads are composed of refrigerators and freezers. Thermal inertia can be utilized here too in load control strategies. Currently, they work with an on/off system. A solution is to modulate the power as a function of the electricity price or of the network conditions. These loads could be associated with storage systems for a better efficiency [1].

Lighting loads: Surveys in the tertiary sector showed that decreasing light by approximately 30% in buildings does not harm visual comfort of the employees [5].

Others equipments: These loads are composed of television, audio systems, and computers. Generally, these equipments are not controllable, except some computer applications, equipped with inverters.

Thermal loads seem to represent the most promising applications concerning load control. The thermal inertia of these loads would enable to cut or to decrease the alimentation of these applications. These loads are already used in some DSM programs. Nevertheless some parameters must be respected such as customer comfort, or standards. Moreover, as their proportion in residential and tertiary sectors is significant, they would allow a possible contribution to Ancillary Services if users could be sensitized on their energy consumption.

Potential for a more optimal control scheme seems to exist in industrial, commercial, and tertiary sectors because loads in these sectors have a high amount of power. In the industrial sector, possibilities are different depending on the application and the process. In tertiary and commercial sectors, a potential for increased controllability exists especially with lighting loads, where decreasing light level would not alter users' comfort.

Finally, concerning the residential sector and its associated small loads (electrical goods, lighting loads) the actions to be taken are linked to energy management. It is always better to consume less, but it would be more efficient to use energy in a more efficient way.

Load Models

To develop load control algorithms, models are required to describe the different loads. Depending on the aim of the control, and the amount of loads, various models can be used. Because of the large diversity and distribution of loads, a single model is hard to establish, and different models have been proposed to achieve various control criteria. According to this aim, a classification appears between static and dynamic models. The first one links active/reactive power to frequency/voltage without time dependence, whereas the second one takes into consideration frequency/ voltage as a function of time.

Static models

A basic relation for static models is the ZIP model, described by equations (1). Equations are divided in three terms containing constant power, constant current and constant impedance.

$$P = P_0 \cdot \left[a_1 \cdot \left(\frac{V}{V_0}\right)^2 + a_2 \cdot \left(\frac{V}{V_0}\right) + a_3 \right] \quad Q = Q_0 \cdot \left[a_4 \cdot \left(\frac{V}{V_0}\right)^2 + a_5 \cdot \left(\frac{V}{V_0}\right) + a_6 \right] \qquad (1)$$

V_0, P_0, Q_0 are initial conditions values, and coefficients a_1 to a_6 are the model parameters.

Another static model, described in relations (2), is the exponential model, where power is voltage dependant.

$$P = P_0 \cdot \left(\frac{V}{V_0}\right)^{np} \quad Q = Q_0 \cdot \left(\frac{V}{V_0}\right)^{nq} \qquad (2)$$

P_0, and Q_0 are initial power values; np and nq, are models parameters. Table 1 presents usual values for the exponents of (2) for different loads [6].

loads	np	nq
Air conditioning	0.5	2.5
Electrical Convection Heater	2	0
Fluorescent lamp	1	3
Pumps, fans, little motors	0.08	1.6
Large industrial motors	0.05	0.5
Little industrial motors	0.1	0.6

Table 1

Dynamic models

To describe dynamic behaviour of loads, differential equations have been developed.

One example is a load model with exponential covering, where active and reactive powers have a non linear relation with voltage. Equations (3) describe the model:

$$T_p \cdot \frac{dP_r}{dt} + P_r = P_0 \cdot \left(\frac{V}{V_0}\right)^{\alpha s} - P_0 \cdot \left(\frac{V}{V_0}\right)^{\alpha t} \quad P_l = P_r + P_0 \cdot \left(\frac{V}{V_0}\right)^{\alpha t} \qquad (3)$$

V_0 and P_0 are voltage and power before voltage variation; P_r is the covering active power, P_l is the total active power response, T_p is the covering constant time, αt is the transient dependence between active load and voltage, and αs is the steady state dependence.

Finally a simpler model presents load linked to voltage and pulsation by relations (4):

$$P = P_0 \cdot V^{pv} \cdot \omega^{p\omega} \quad Q = Q_0 \cdot V^{qv} \cdot \omega^{q\omega} \qquad (4)$$

Table 2presents some values for the exponents of (4), for different loads [7].

Loads	exponents			
	Pv	qv	pω	qω
Incandescent lamp	1.55	0	0	0
Fluorescent lamp	0.96	7.38	1	-26.6
Air conditioning	0.2	2.3	0.9	-2.67
Dryer	2.04	3.27	0	-2.63
Refrigerators and freezers	0.77	2.5	0.53	-1.46
Little electrical goods	2	0	0	0
Pumps and fans	0.08	1.6	2.9	1.8
Radiators	2	0	0	0
TV, audio systems, computers	2	5.2	0	-4.6

Table 2

LOAD CONTROL ALGORITHMS

Study cases: generalities and conditions

To evaluate the potential of load control to adapt to intermittent production, two versions of an adaptive consumption algorithm have been established, implemented, and tested in Matlab. They have been simulated on a small distribution network (Figure 2), including 25 residential customers, and a supermarket, with power generated by a

small windmill. This pool is more precisely composed of 49 loads, in which 25 are **controllable**, and 24 are **critical**. The test's run-time was 24 hours, with a 10 minute time step.
These algorithms aim to ensure balance between production and consumption for consumption shifting, or limited production. The supposed development of NICT considers that each user owns device which enable individual control of each load of each user (Figure 3). By controlling interruptible loads, it will be possible to adapt consumption to fluctuating production.

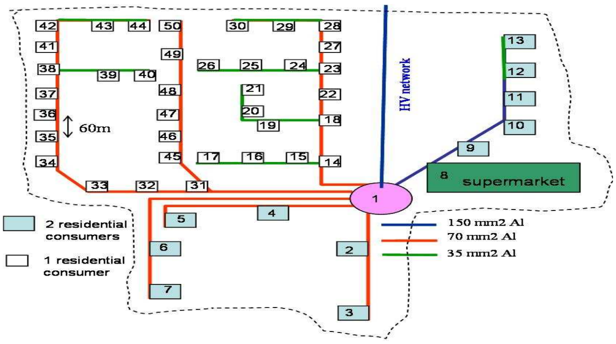

Figure 2:distribution network for simulations

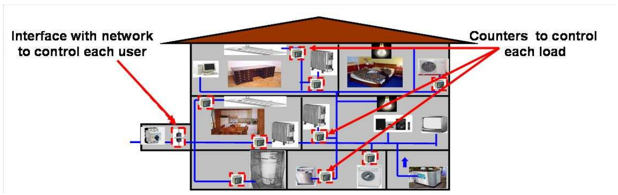

Figure 3: device in each residential user's home

Simple adaptive consumption algorithm

The principle of the simple load control algorithm is depicted in Figure 4.

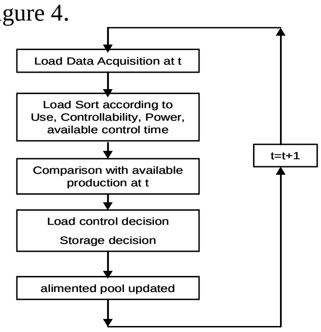

Figure 4 algorithm synoptic

Assuming that necessary requirements for communication, metering, and control including NICT will be available in a future network, loads data are first gathered at each time step. Next loads are sorted according to different criteria, in the following order: use, controllability, power, and available control time. The resulting list is compared to the available production for this time step. Depending on the difference between consumption and production, if production is lower than consumption, control signals are sent to controllable loads. If production is higher than consumption, excess production, is lost, stored, or even could be fed back into the network.
After this load control or storage decision, loads data are up dated, and gathered again for the next time step.

Adaptive consumption algorithm with preponing and postponing

An improved version of this algorithm takes into account predictable and deferrable loads. This algorithm begins as the previous, by sorting loads with the same criteria. The improvements consist in two additional tests, in the case of more production than consumption.
In the first algorithm, when consumption exceeded production, some loads were not supplied, and this delay could not be made up. Here, loads are supposed to be equipped with a counter which increases by one each time step loads are not supplied. Afterwards, if production will exceed consumption, these loads, which are late, will be supplied if they are deferrable and if they are not predicted to be supplied at this time step.
The second test aims at feeding some foreseeable loads in advance. For a given time step, if some loads do not demand to be supplied and are foreseen to be used later, they are delivered, and the counter value decreases by one earlier.
After these two tests (on supply delayed and foreseeable loads) loads data are gathered again for the next time step.
The aim of the second version of the algorithm is to use all the production available, at each time step. Electricity can hardly be stored, and in case of an islanded network, electricity cannot return into the network.

RESULTS

Figure 5which presents the simulation conditions shows a fluctuated consumption curve. Indeed, the proliferation is weak, and there are few loads.

Simple adaptive consumption algorithm

Figure 6 shows the outcomes of the basic algorithm. In the considered case study, it appears that if total consumption cannot be satisfied, it is generally possible to provide energy to critical loads, at each time step.
One more important result, which will later justify the second algorithm, is that a vast amount of energy is lost, stored, or returned into the network, depending on the hypothesis. Often, the curve of stored or lost production is not null. The main reason is that production and consumption peaks rarely coincide.
The general result of this algorithm is that provided power is equal to the minimum between available production and total consumption.

Adaptive consumption algorithm with preponing and postponing

The second algorithm was tested in the same simulation conditions as the first. The results are presented in Figure 7. The graph shows that available energy is used in best way. Only a small amount of energy is lost or stored. The stored or lost production curve is null nearly the entire day, except during the night, when consumption falls.

As mentioned before, production and consumption peaks do not coincide, so some loads are supplied in advance, others are delayed. In consequence, even if the delivery plan is not optimal at every step, the total delivery is satisfying.

The general result of this improved algorithm is that consumption is adapted to production almost continually.

Figure 5:production and total consumption for the simulations

Figure 6:supply and stored or lost production for the basic algorithm

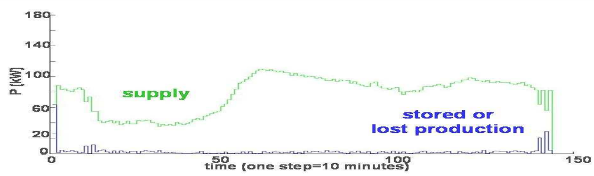

Figure 7:supply and stored or lost production for the improved algorithm

Comparison between the two versions

Figure 8allows comparing the two solutions of load control, in relation to consumption on the left side, and to production on the right side. Results of this comparison are more qualitative than quantitative, but show which potential benefits are represented by preponing and postponing load control.

As it has been said earlier, the conditions are the same for both simulations; there is a 6% deficit of energy.

The basic algorithm satisfies only three quarters of the demand, although nearly 20% of the production is lost, stored or fed back into the network.

The improved version allows to satisfy more than 90% of the demand, and to use almost all the production (only 3% is lost).

Results are promising in using load control to counteract uncertainty of limited or intermittent productions.

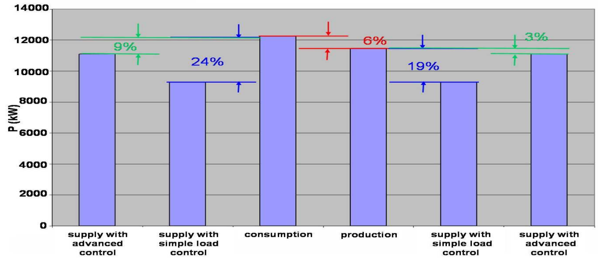

Figure 8: comparison between the two algorithm versions

CONCLUSION

This work illustrated how in the future load control could help to ensure Production/Consumption balance, in order to mitigate production uncertainty, in case of limited or intermittent production. A classification has been first presented, introducing notions such as “controllable loads”, “pre”, “post-shiftable loads” or “critical loads”. Then, to describe these loads, mathematical models have been recalled. Finally, two versions of an adaptive consumption algorithm have been implemented in Matlab. They aim to ensure production/consumption balance by controlling loads. The second is an improved version of the first one, because it tries to use all the available production at each time step. To ensure this balance adequate equipment for measurement, communication, and control must be implemented. Results of these algorithms show that load shedding could help efficiency for production/consumption balance. Moreover, by controlling specifics charges, it will be possible to provide some kind of load reserve, and consequently to help to maintain distribution network reliable and safe, even under more and more critical operating constraints related to grid evolutions.

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