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# An Intelligent System for Decentralized Load Management

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***Abstract*** – *This work proposes a model of an intelligent short term demand side management system based on a MAS. The system is designed to avoid peaks of power request greater than a given threshold and to give maximum comfort to user. The proposed system is composed of a distributed network of processing nodes (PN). Each PN hosts one agent and it is able to manage a single socket tap allowing or disallowing it to supply power. Each agent reacts to a new critical condition entering in competition with the others to gain the access at a shared limited resource. As the results shown the proposed agency can be the consumer's key to take advantage of a DSM program automatically.*

## I. INTRODUCTION

The changes in the utility industry both in home and commercial sectors due to deregulation, new technologies, and increased global competition are well known. The electric power grid was historically operated by separate utilities, each independent in its own control area and regulated by local bodies, to deliver bulk power from generation to load areas reliably and economically. As a non-competitive, regulated monopoly, emphasis was on reliability (and security) at the expense of economy. However, this infrastructure, faced with deregulation and coupled with interdependencies with other critical infrastructures and increased demand for high-quality and reliable electricity for our digital economy is becoming more and more stressed.

To effectively deal with these changes, energy providers and consumers alike require new levels of capability for management and control of their energy systems. Providers require detailed information about usage patterns to enable efficient management and pricing of energy production. And consumers require the ability to understand their own energy usage needs to be able to control consumption and negotiate and verify rates.

Over the last few years Demand-side management (DSM) systems are becoming very common in many countries. Demand-side management (DSM) refers to measures implemented by utilities that modify end-use electrical energy consumption, either reducing overall consumption through energy efficiency or using load management to reduce demand at times when the cost of reducing demand is less than the cost of servicing it [1].

Load management programs tries to achieve an approximately constant energy consumption that meets the characteristics of power stations. It is well known that the typical energy consumption of users is very far to meet this request. To cover this gap, load management programs involve reducing loads on a utility's system during periods of peak power consumption or allowing customers to reduce electricity use in response to price signals. Such programs use mechanisms like interruptible load tariffs, time-of-use rates, real-time pricing, direct load control, and voluntary demand response programs.

There are already simple DSM-solutions with programmable timers for each household appliance, but they cannot be used for more complex problems and they are essentially static.

This study proposes a model of an intelligent short term DSM system based on an multi agent system (MAS). The feature of a MAS particularly stressed in this work is its ability to provide an environment in which agents can communicate among them to solve a problem. Each agent knows its local condition and become aware of the overall system condition by communicating with other agents.

It is well known that each MAS must have an objective function. The object function of the proposed MAS aims to implement a smart power management system tuned on the Italian power provider constraints on residential consumers. This power management system can be easily tuned to handle constrains of other power providers, according to the new scenario introduced by the deregulation.

It is noteworthy that the proposed approach is generalizable to handle the whole class of problems known as "producer/consumer". Indeed, the actions of each agent and the policy of the coach can be tuned to handle other problems such as, for example, scheduling for a grid computing system [2].

The aim of this work is to study the behavior of the MAS while it is handling critical conditions. For this reason, a simulation was realized by means of Matlab Simulink®. While this approach neglects some aspects of the problem (such as data logging, digital signal processing of gathered raw data, etc.), it is useful to evaluate the overall behavior of the system that is the most interesting aspect for the end user.

This work is organized in five sections. Section II describes the proposed system. Section III shows the characterization of the electric loads used for the proposed model while section IV presents the results obtained, finally conclusions and future works are included in section V.

## II. SYSTEM OVERVIEW

This work proposes a DSM solution based on a MAS. The Italian provider offers contracts that allow consumers to use electric power till a limit of 3 kW. If a consumer exceeds this limit, the outcome is an outage, that will last until the user's power request is greater than 3kW. In this work this value of load will be called "critical load" and an overall power request greater than this value will be called "critical condition".

The agency tries to find a consumption policy that achieves two main targets:

1. not requesting more than 3 kW
2. giving maximum comfort to user.

These targets are achieved through the competition of more agents each one managing a socket tap.

The approach proposed by this DSM System is not limited to private households. It can be also used in large business facilities, machine halls and wherever electrical appliances are in use.

For example, the Italian provider offers to business facilities contracts that have not the limit of power consumption, but they have a pricing that grows as the power request grows. In these cases the presence of a system that limits the load automatically can be an effective strategy to save energy and money.

The proposed system is composed of a distributed network of processing nodes (PN). Each PN hosts one agent and it is able to manage a single socket tap allowing or disallowing it to supply power.

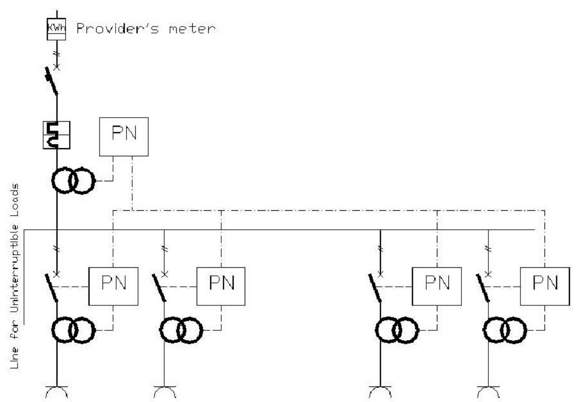


Figure 1 – Wiring diagram of the proposed system

Each intelligent agent knows the load curve of the appliance connected to its socket tap and those of the active appliances connected to all the other agents. Actually the load curve is an input parameter computed as explained in the previous section. These load curves are used by the system to predict critical conditions and avoid them.

At each instant of time, the load curves of all the active appliances are stored in a table (table of loads) shared among all the agents [4]. Another shared information among all the agents is their own state concerning a given critical condition.

Figure 1 shows the wiring diagram of the proposed system. The symbols adopted are in compliance with the CEI 3-14. This diagram highlights how each PN is connected with each socket tap while in figure 2 there is a block diagram of a PN.

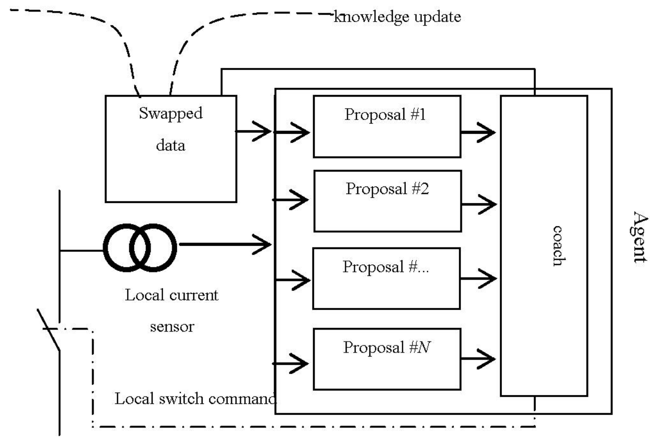


Figure 2 –Logic diagram of each Agent

The system is a short term power management system. It processes the table of loads to forecast critical conditions and reacts to avoid them. If the system forecast a critical condition, it will react to this event starting a negotiation phase among all the agents in order to find a new configuration in which some appliances are switched off.

A fundamental constrain for this system is that not all the devices have to react at each event, but as many as there are necessary to avoid a critical condition.

A key point is the way in which the system chooses what devices have to be switched off. This choice has to achieve two main targets:

1. the overall power request has to be less than the critical load. On the other hand, the selected choice should have an overall power request as close as possible to this limit.
2. give to user the maximum comfort. This means that the system should satisfy as many user requests as possible.

In order to find the load configuration that achieves these targets, each agent evaluates different strategies.

The difference among these strategies is the method they use to give the priority to each appliance. In this work the authors confined themselves to evaluate three strategies:

1. User defined priority (the first method in Figure 5): user attributes a different level of priority to each appliance. Currently five classes of priority are defined. Each class can contain twenty devices. The devices belonging to the highest priority class can be never stopped.
2. The priority is automatically assigned to each appliance. The priority level for each appliance is directly proportional to the power that it consumed in the last period (the second method in Figure 5).

3. The priority is automatically assigned to each appliance. The priority level for each appliance is directly proportional to the power that it will consume in the next period (the third method in Figure 5).

The last two methods are useful to optimize the energy consumption of the system. Indeed, typically the biggest loads are requested by appliances that are heating something (i.e. a dishwasher that is heating the water). If, for any reason, an appliance is interrupted in this phase, the results will be a waste of energy due to the loss of heat.

Each agent processes the table of loads in order to forecast critical condition, but each agent can influence only the appliance connected to it. For each method there is a copy of the table of loads and all the actions are performed on this copy. When the negotiation phase is over the table of loads handled by the winner method become the current table of loads for all the methods.

Each agent computes the following algorithm using one of the methods defined above:

1. Search for a critical condition in the next *T* columns of the table of loads.
2. If a critical condition is found at the column *I*
   - i. The agent handling the appliance with the lowest priority that has no reacted to this event shifts its load curve of one column starting from the column *I*
   - ii. Repeat (i) until the critical condition is avoided.
   - iii. The coach chooses the best solution and update the table of loads of the losing methods with that of the winner method.
3. Go to point (1).

The best solution:

- Avoids the critical conditions
- Has the biggest number of appliances that complete their load curve in the next *T* columns. This allows the system to complete a major number of loads and simplifies the management of the remaining loads.
- Maximizes power consumption in the next *T* columns. This means satisfying as many user requests as possible.

The first property is a absolutely necessary condition but the others are not so. The second property has a priority greater than the third one.

*T* is a parameter of the simulation that can be critical in the hardware implementation phase of the model because it is directly proportional to the computational load of the system. The results shown in the next section are obtained using *T* equal to twenty namely a forecast period of forty minutes.

## III. LOAD CHARACTERIZATION

In order to define an accurate model of a power management system, it is mandatory to define an accurate characterization of the load introduced by each electrical appliance.

A graphic illustration of the daily load profile is the 24-hour chronological load diagram shown in Figure 3 [5].

This figure does not claim to be a precise description of the phenomena and to have a general validity. Yet it can be useful to draw some conclusions that have general validity:

- The most obvious and the most useful one for the proposed system purposes is that the load has not a constant value, but it has more than one peak load and more than one troughs. In order to equalize this trend the system has the ability to postpone the satisfaction of some power requests.
- There is always a base load. For a residential consumer this base load can not be constant in the time. For example, just thinking of a house with only the refrigerator (that is a variable load) and some other small appliances on (i.e. alarm, appliances in stand-by and so on). In the proposed model, the base load is modeled using an uninterruptible variable power request. This base load includes also some small loads such as the house lights.

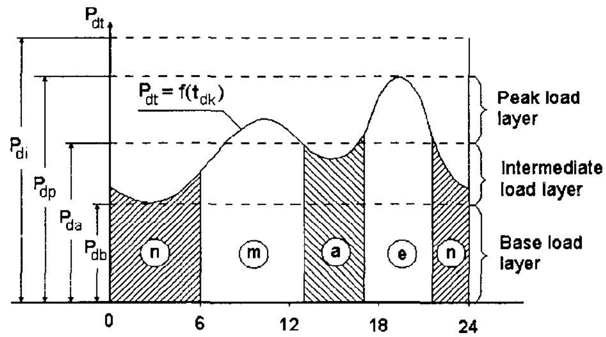


Figure 3 - Example of daily profile [3]

Another important issue of concern is the modeling of the load for each household appliance.

In the proposed simulation, three kinds of load have been modeled:

- Constant load: there are many appliances that can be modeled in this way such as hairdryer, TV, etc.
- Loads varying between two values: a typical example of this class of appliance is the electric oven. Its load has a constant value greater than zero until its temperature is less than a desired value then its load is zero while the temperature is greater than another value and so on.
- Load varying among many values: there are many appliances that belong to this class of load. For example: washing machine, dishwasher, etc. The load of this kind of appliances is related to the program that they are running. Furthermore these appliances are characterized by the ability to execute more than one program. For this reason it is difficult recognize an appliance from its load curve.

In this work the load curves, used to test the simulator, were sampled using real household appliance and a sample time of 2'.

## IV. EXPERIMENTS

In order to test the system, a lot of experiments were carried out using different loads. In this section there are the results, obtained using the following parameters and the power requests shown in Figure 4.

- Number of agents equal to five
- Each agent handles a single socket tap
- On each socket tap only a household appliance at time can be active
- *T* is equal to twenty
- Base load variable between 0 and 1.05 kW as shown in the sixth row of the .

Figure 4 shows how five load requests are satisfied by the system in presence of a base load using the previous parameters. In this figure there is a row for each agent and the last row shows the overall power request. The first column shows the requested loads while the second column shows how these requests are satisfied. It is noteworthy how the sixth load (namely the uninterruptible base load) is satisfied in real time, while all the other charges are interrupted many times.

The fourth row is a load varying between two values, while the others are loads varying among many values.

The first column of the seventh row highlights the overall power request while the second column of the same row shows how it is satisfied.

It is clear that there is a simultaneous request for a big load that can generate a power outage without using the proposed system (first column). The second column shows how the proposed system manages this situation.

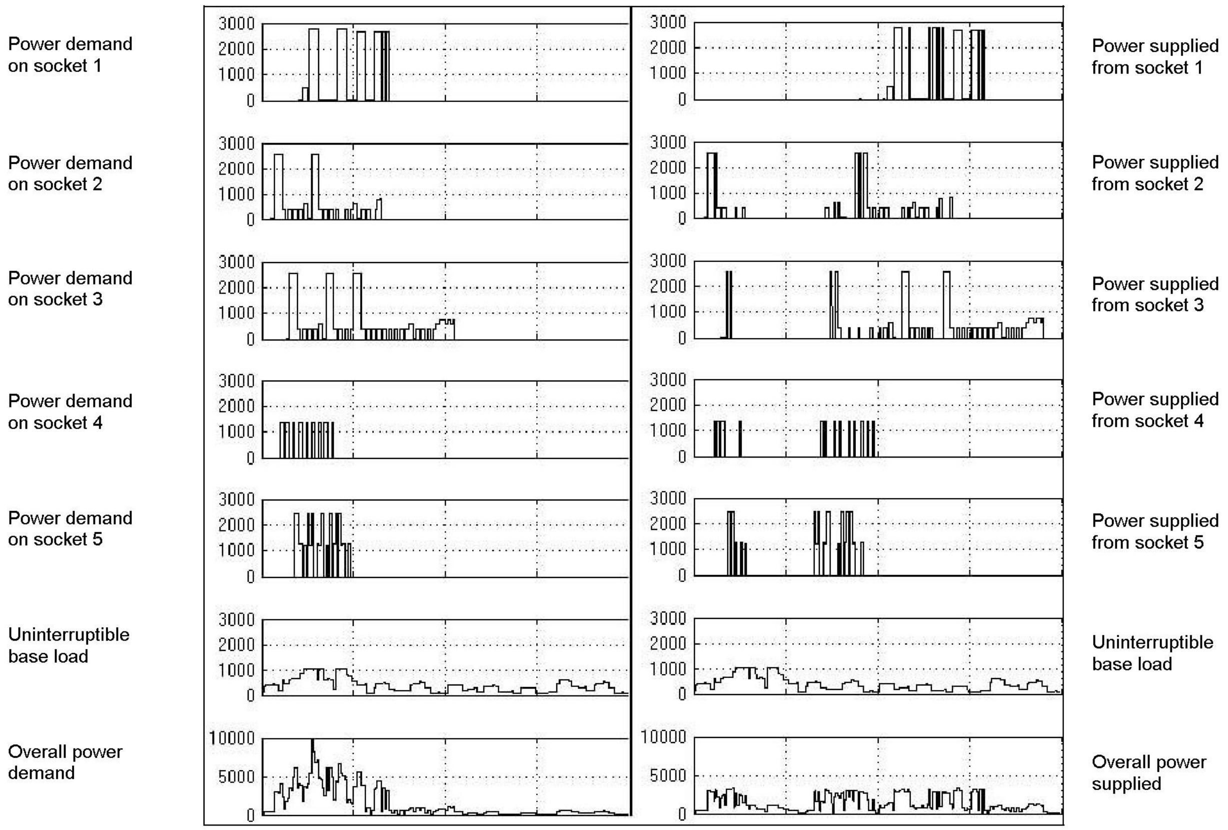


Figure 4 - This figure shows how five load (the first five rows) requests are satisfied by the system in presence of a base load (the sixth row)

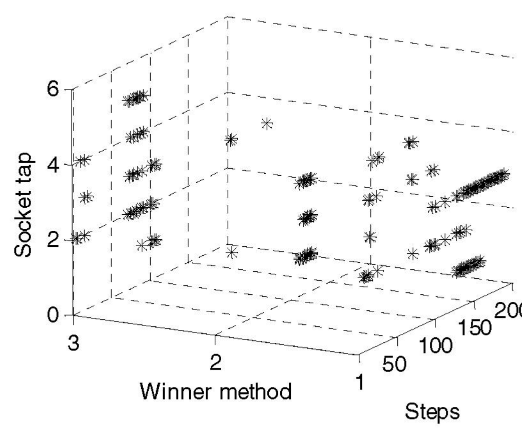


Figure 5 – Competition among the various methods while the system is handling the five load requests shown in Figure 4. During the competition phase the state of socket taps do not change

The base load is satisfied without interruptions, while all the other loads are interrupted and delayed according to the algorithm described above.

The effects of the proposed system are that: the peaks are smoothed, the power consumption is well distributed in the time and there are not outages. Figure 5 shows the competition among the various methods while the system is handling the five load requests represented in Figure 4. In Figure 5, for each time there is a stair for each active socket tap.

These stairs are positioned in correspondence of the winner method. A strong competition among the various methods is noticeable. This happens because the power requests used in this experiment are very high and so the system has to handle several critical conditions. The average number of messages exchanged among the agents to manage a single critical condition is fifteen.

## V. CONCLUSIONS

This work proposes a model of an intelligent short term DSM system based on a MAS. This system can be the consumer's key to take advantage of a DSM program automatically.

The system is designed to achieve two main targets:

- The overall power request must be less than a given threshold (3kW for Italian provider)
- Giving maximum comfort to user.

The effects of the proposed system are that: the peaks are smoothed, the power consumption is well distributed in the time and, for italian users, there are not outages risen from the overcoming of the 3kW limit.

The proposed system manages the load requests by means of the competition among various agents. Each agent reacts to a new critical condition entering in competition with the others to gain the access at a shared limited resource.

The main advantages of this system in comparison with a system based on the simple user defined priority are:

- It has a great flexibility, indeed user can define a set of devices as uninterruptible loads.
- It gives a big power reliability because it is able to avoid the critical conditions.
- Its behavior is not predefined by the user, but it is dynamically determined by the competition among various agents.
- The proposed consumption strategies aim to fulfill both user's whishes (defined by means of the user defined priority) and the intrinsic constrains introduced by the state of work of each household appliance.

Nowadays load curves sampled using real household appliances are used as input to test the system. Since one household appliance, such as a washing machine, can have more than one load curve, future works will add the ability of sampling and storing many load curves to each agent. In this way the agent can try to recognize an ongoing power request and it can associate to it a stored load curve. Therefore, the table of loads will be dynamically and automatically built.

From the point of view of a physical implementation of the proposed system, it seems that there are not big technology problems. Small and cheap processors are available and the technologies to enable information interchange among the agents are available and well tested (for example see: [6, 7]).

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