Swarm Grid: Collective synchronization of electricity grid devices

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Abstract

The electricity grid has to respond to large power variations in relatively short periods of time. This behavior causes an inefficiency operation and design of the electricity system. The Demand Side-Management techniques are used to modify the power demand, reducing or smoothing its shape. Moreover, the electricity grid is a very huge system composed for millions of devices. There are problems associated with the density and distance between elements. The development of new technologies has increased the complexity of the grid in the last years. In this framework, the Smart Grid arises.

The inclusion of communication technologies into the grid allows a better monitoring and control of the system. Smart Grid systems must be able to manage thousands or even millions of devices to increase the efficiency of the electricity grid, but they have also to satisfy the classical grid constrictions. The amount of information and calculus of the Smart Grid management system should be reduced. For these reasons, our studies about the electricity grid synchronization are based on a distributed design. Specifically, they are focus on the Swarm Intelligence theory. The Swarm Intelligence theory is inspired on biological systems, concretely on the self-organized behavior of several species. The elements or agents follow very simple rules sensing the local environment and with a certain random degree. For these reasons, these algorithms are good candidates to solve the problem of the electricity grid synchronization, creating what we have called the "Swarm Grid".

The aggregated consumption of the grid is a time variant function with peaks and valleys. The electricity grid generation has to follow this function in order to supply the power demand. An example of the typical aggregated consumption for a weekly day in Spain is shown in Figure 1. Therefore, the electricity grid has to respond to large power variations in relatively short periods of time. This behavior causes an inefficiency operation and design of the electricity system. On the operation side, there is a poor performance because of generation power swings: generation must always supply power demand, therefore abrupt changes in the demand cause generation power swings, together with increases in operation stress and losses. On the design side, the electricity grid must be sized to supply the peak power demand: the power difference between valleys and peaks implies that the electricity grid must be over-sized. Several power plants and lines are designed to supply the power demand during the peak hours and they are not used during the rest of the day.

One technical solution to minimize these problems is to flatten the power demand curve, reducing the difference between peaks and valleys. The techniques used to modify the power

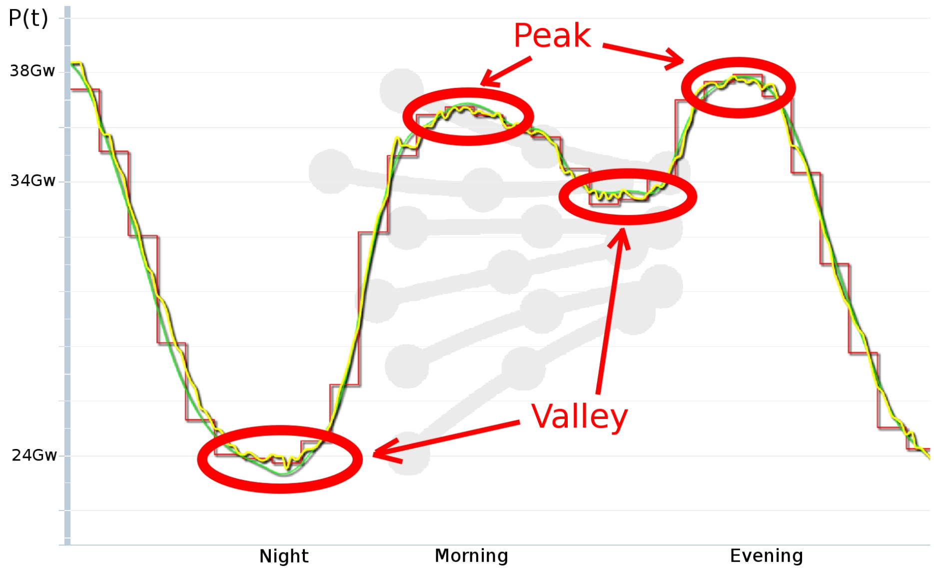

Figure 1: Aggregated consumption of a typical weekly day in Spain. Source: Red Eléctrica Española.

demand are called Demand-Side Management (DSM) techniques. They are used according to four different goals: i) to reduce the power consumption, ii) to reduce the power consumption during peak hours, iii) to increase the power consumption during valley hours or iv)to displace the consumption from peak to valley hours. These techniques are commonly focused on the house or industrial common consumption management (e.g. lighting, computers, washing machines). Nowadays, given recent technological advances in decentralized generation and storage, DSM should also include new local generation and storage technologies like photovoltaic energy, lead-acid/Ni-Cd batteries and electrical vehicles.

In previous work carried out by the Renewable Distributed Generation and Intelligent Control research group, the development of DSM techniques has been focused on the operation of a single installation in the GeDELOS-PV system framework. GeDELOS-PV system is a real example of the added-value of PV electricity that combines the last generation of PV grid-connected systems, small-scale electricity storage, DSM strategies and a complete monitoring and actuation system [1]. Its main objective is to satisfy the final user electricity needs while optimizing local energy self-consumption, through the combination of two complementary strategies focused on the load profile (daily pattern can be modified to better match the expected PV generation pattern) and local storage management (only surplus of generated electricity is stored for later use in hours of low/zero generation) [2, 3, 4]. Through GeDELOS-PV system the interaction with the electricity grid is reduced, satisfying one of the DSM goals. Despite the energy exchanges between the electricity grid and a single installation are reduced, it is not synchronized with the rest of the elements of the grid. Hence, a system to coordinate the whole grid is necessary if the advantages arising from the combination of local generation, storage and load demand are to be extended to multiple users.

The electricity grid is a very huge system composed for millions of devices. There are problems associated with the distance between elements, e.g.: a power plant has to supply several devices that are hundreds of kilometers away. Other problems are associated with the distri-

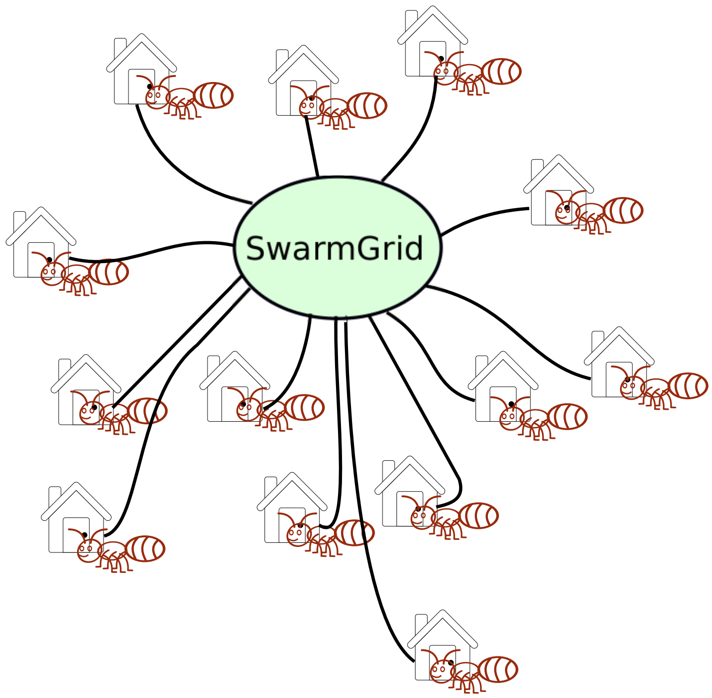

Figure 2: Smart Grid managed by a swarm intelligence algorithm conceptual scheme.

bution of the consuming elements, having areas with very high or low density. Moreover, the development of new technologies increases the complexity of the grid e.g.: distributed generation, local storage systems, electrical vehicles. With the aim of solving current electricity grid management problems and gradually introducing sustainability and rational use of resources into electricity networks, the Smart Grid arises.

Smart Grid systems must be able to manage thousands or even millions of devices to increase the efficiency of the electricity grid, but they have also to satisfy the classical grid constrictions. The electricity grid must be robust because the production and the way of a whole country depend on it. This implies that a Smart Grid management should not be centralized in a single location: the system must respond quickly to generation or demand variations because the electricity supply must always be satisfied. Therefore, the amount of information and calculus of the Smart Grid management system must be reduced. For these reasons, our studies about the electricity grid synchronization are based on a distributed design. Specifically, they are focus on the Swarm Intelligence theory. The Swarm Intelligence theory is inspired on biological systems, concretely on the self-organized behavior of several species. The elements or agents follow very simple rules sensing the local environment and with a certain random degree. Although there is no centralized control structure dictating how individual agents should behave, interactions between such agents lead to the emergence of an “intelligent” global behavior, unknown to the individual agents. When these algorithms are applied to engineering problems, they achieve global solutions with high robustness and a low information exchange. For these reasons, these algorithms are good candidates to solve the problem of the electricity grid synchronization, creating what we have called the “Swarm Grid” (see Figure 2).

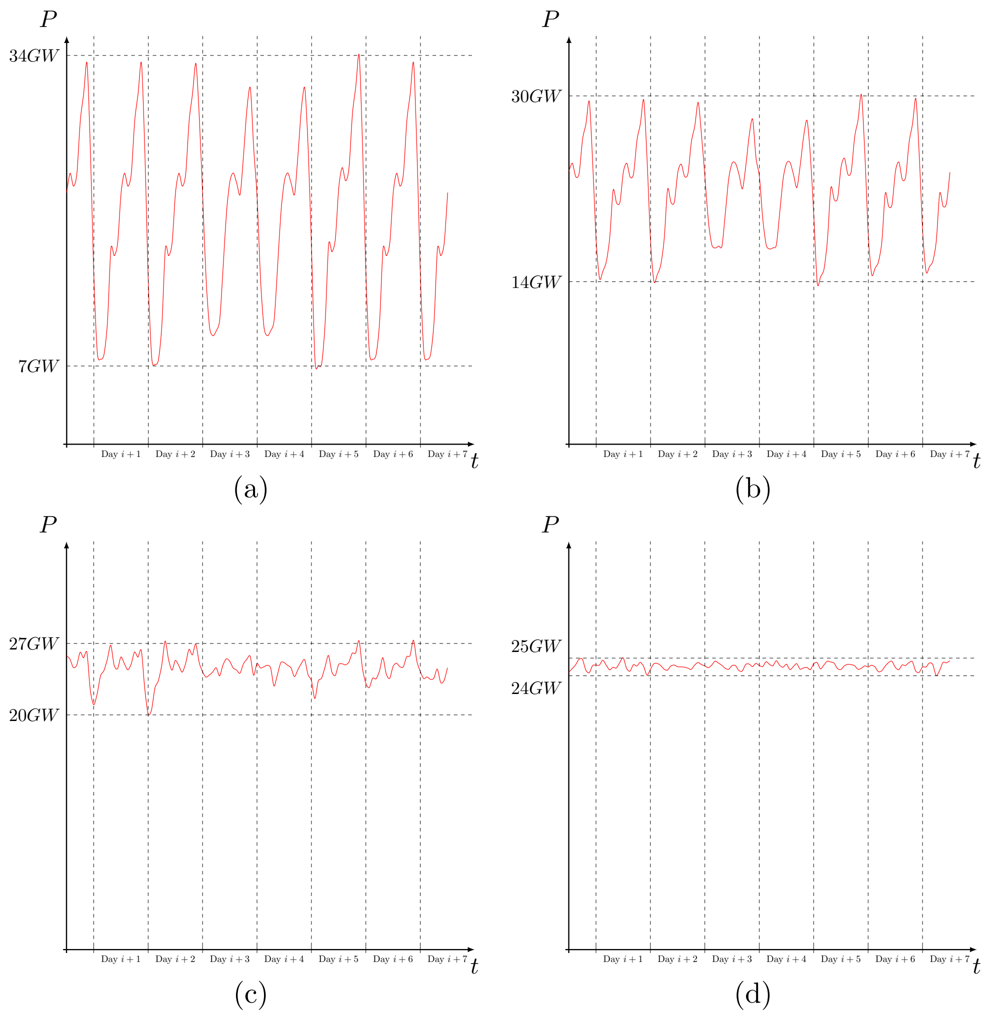

Figure 3: Operation example of the swarm intelligence algorithm for Smart Grid management: a) without controllable consumption, b) 25% of controllable power consumption, c) 50% of controllable power consumption and d) 100% of controllable power consumption.

We consider the devices connected to the grid like elements of a huge swarm. These elements are able to sense information about the electricity grid status, in the same way that insects of a colony sense information from the environment. Every element modifies stochastically its own consumption and taking into account the sensed information, follows a swarm intelligence algorithm. This algorithm indicates how each device connected to the grid has to demand power through a probability distribution.

We have developed this algorithm and we have applied it into an electricity grid simulator. Our experiments are focused in the residential sector, where several users demand power from the electricity grid activating different electrical appliances. When a user activates a device that can be controlled by the Swarm Intelligence algorithm, it decides when it must be started according with the electricity grid status. An example of the swarm intelligence algorithm operation can be observed in Figure 3. We have tested how the increase of the power amount controlled by the algorithm affects the grid. Firstly, the grid operation without controllable power is shown in Figure 3a (the actual situation). Secondly, a 25% of controllable power has been introduced in the electricity grid and the result is shown in Figure 3b: the difference between peaks and valleys has been considerably reduced (41% in relation to reference case a) by the use of the swarm intelligence algorithm. Finally, the amount of controllable power has been increased to 50% and 100% and the results are shown in figures 3c and 3d respectively (reductions of peak-valley consumption of 74% and 96% respectively, relative to reference case a).

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