Follow The Leader in a Consensus Network as a Solution to Manage an Smart Grid: The Balearic Islands Case

(Demonstration)

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1. INTRODUCTION

The problem of managing an electrical network has been growing in interest and importance. It represents a meaningful part of the GDP of a country and it is an strategic sector essential for the rest of the economic activities. In this work, we have focused on the demand management. Electrical energy cannot be stored in large quantities, so the amount of energy required must be generated when it is demanded. How can we distribute this demand among the components of the network so this demand is fulfilled? and, how can we overcome failures in any substation so that the rest of the available network can compensate the lost? Those problems are face in this work with the added difficulty that we must solve it with only local information.

We have modeled the energy network as a multiagent system, where each substation is modeled as an agent that can communicate only with the agents corresponding to the substations it is directly connected to. This multiagent system uses a consensus process to adjust the provided power to the current demand, whereas a gossip algorithm calculates, at the same time, the current total number of active stations and the required capacity of the network.

As a case study to show the performance of our solution, we have made a demo application[1] that, using the electrical network in Balearic Islands (Figure 1) and some historic information of the real demand, shows how the network provides the required demand and how it quickly adapts to failures in power substations.

[1]http://www.youtube.com/watch?v=NVGbgLvR5wc

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Figure 1: Electrical network in Balearic Islands. The color of the lines represents its capacity

2. PROPOSED MECHANISM

The proposed mechanism is a combination of two belief propagation methods: Push-Sum algorithm [1] and consensus processes [2].

Push-Sum algorithm is one of the *gossip-based* or *epidemic* protocols that have emerged as a way to share information to make some global calculations in a decentralized way. Each agent i is characterized by a value $s_i(t)$ and a weight $w_i(t)$. These values are divided among the agent and its neighbors and the new values are calculated as:

$$\begin{aligned} s_i(t+1) &= \frac{s_i(t)}{d_i+1} + \sum_{j \in N_i} \frac{s_j(t)}{d_j+1} \\ w_i(t+1) &= \frac{w_i(t)}{d_i+1} + \sum_{j \in N_i} \frac{w_j(t)}{d_j+1} \end{aligned} \quad (1)$$

The quotient $s_i(t)/w_i(t)$ converges to $\lim_{t\to\infty} \frac{s_i(t)}{w_i(t)} = \sum_i s_i(0)$ when $w_i(0) = 1\ \forall i$

Consensus algorithm allows a faster convergence rate than the push-sum, so it is used to adapt to the demand. In each step, agents exchange its current values with their neighbors. The process converges to the average of the initial values $x_i(0)$ of the agents. The dynamics of the system is modeled as follows:

$$x_i(t+1) = x_i(t) + \frac{\varepsilon}{v_i(t)} \sum_{j \in N_i} [x_j(t) - x_i(t)] \qquad (2)$$

where N_i are the neighbors of agent i, $v_i(t)$ is the weight of agent i, and ε is a constant that defines the learning step. The process converges to $\lim_{t \to \infty} x_i(t) = \frac{\sum_i w_i x_i(0)}{\sum_i w_i}$ under certain conditions.

The consensus framework offers the possibility of control the complete MAS using a particular, 'leader' agent that evolves independently of the other agents in the network. All the rest of agents converge to the state of the leader. and the rest of the agents converge to the state of the leader as time goes on. This problem is commonly known as 'The Leader-Following Consensus Problem'.

These mechanisms are combined as follows. Push-sum algorithm and consensus algorithm run in parallel, so the information required by both processes can be exchanged in one, unique message. Let be $s_i(0) = 1$ the count for stations, $ws_i(0) = 1$ (indicates push-sum algorithm an aggregation of values); $c_i(0)$ initialized with the capacity of substation i, with $ws_i(0) = 1$; x_i is the variable that contains the total demand of the network and v_i the proportion of the total capacity of the network provided by agent i. In each iteration, agent i sends a tuple

$$\left(\frac{s_i(t)}{d_i+1}, \frac{ws_i(t)}{d_i+1}, \frac{c_i(t)}{d_i+1}, \frac{wc_i(t)}{d_i+1}, x_i(t) \right) \qquad (3)$$

to all its neighbors.

Push-Sum is used to keep the track of current active agents as aggregate value the total number of agents $NA(t) = s_i(t)/ws_i(t)$ and the total capacity of the network $NC(t) = c_i(t)/wc_i(t)$. This information is used by the consensus algorithm to adjust the performance of the individual agents taking into account that each agent has to provide only the proportional part of the whole value that is given from the number of agents currently in the system NA, and the total capacity of the network NC. Therefore, the weight of station i in the system is obtained as $v_i(t) = c_i(0)/NC(t)$. When all the messages have been received, agents updates their values following Equations (1) and (2). After a transient phase, $x_i(t)$ will content the total demand and $v_i(t)x_i(t)$ will be the part of the demand provided by substation i.

We would like to underline that these three values (NA, NC, and the value that is provided for each agent) are calculated at the same time, so that any change in the number of agents (some agents leave the system or enter in it) and in the capacity of the network can be detected and the system adapts to them.

3. BALEARIC ISLANDS CASE

The Balearic Islands electricity network is composed of 57 substations and 82 lines from 30 kV to 220 kV. Substations are in charge of accumulating and transferring power from the power centrals to the final consumers. Table 1 shows some structural properties of the network.

average degree	2.877
average path length	4.786
diameter	14
clustering	0.337

Table 1: Balearic Electrical Network characteristics

Following the open data available, we have modeled a demo where each one of these substations are agents, and we have one additional agent that is the *Leader agent*. This agent is indicating the energy network global demand and we have checked how the multi-agent system following our method approaches this demand even when it is changing (following real data of the existing demand happened at the Balearic Islands) as can be seen at Figure 2. In the left image of this figure, it can observed how the agents follow the demand curve indicated by the leader agent. Right image of this figure shows a zoom view showing how individual agents approach to the value established by the leader agent. The convergence speed to the reference value depends on the network characteristics, being the diameter and the average path length the most influential parameters.

Moreover, the demo application allows to deactivate and reactivate substations checking how the system adapts to these changes. This allows to simulate the failure of substations. The rest of the substations dynamically detect this situation and assume the proportional part of the demand that was provided by the fallen nodes. When the failure in the substations is corrected, the system readapts to the original situation.

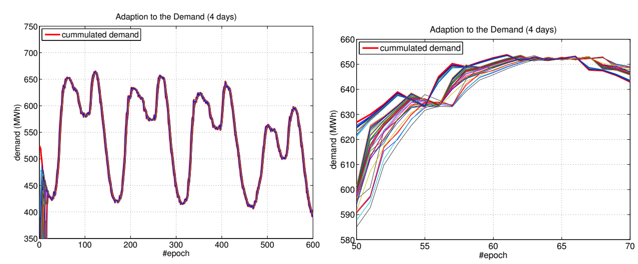

Figure 2: Result of the consensus process (each node adapts dynamically to changes in the demand exchanging information with its direct neighbors only). Right figure is a zoom view of the left one.

4. ACKNOWLEDGMENTS

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5. REFERENCES

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