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An Artificial Immune Network for Distributed Demand-Side Management in Smart Grids

Diego Lizondo[a,b,*], Sebastian Rodriguez[a,b], Adrián Will[a,c], Victor Jimenez[a], Jorge Gotay[a]

[a] Grupo de Investigación en Técnologías Informáticas Avanzadas (GITIA), Facultad Regional Tucumán, Universidad Tecnológica Nacional, Argentina
[b] Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET), Argentina
[c] Facultad de Ciencias Exactas (FACET), Universidad Nacional de Tucumán, Argentina

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ABSTRACT

In this work we present a Distributed Demand-Side Management system based on the Artificial Immune Network algorithm. It implements an intelligent, distributed and autonomous control of the customer's Air Conditioning devices in order to meet the desired demand. The system is particularly adapted to tackle the Peak Load problem that appears in Tropical and Subtropical climates due to the use of thousands of these devices at the same time. The design follows the guidelines set by the Smart Grid paradigm, in the sense that it is fault tolerant, distributed and self-controlled. It requires minimal communication infrastructure when compared to a centralized system.

The algorithm was evaluated using synthetic and real data. We define Maximal and Average Tolerance as performance metrics, and show that the system keeps the consumption within 1% of the given load limit in all 5 cases.

1. Introduction

Energy consumption, and in particular the electric energy consumption, has grown steadily over the last few years, due to the natural increase of the population and new technologies [29]. In this new scenario it is necessary to improve the features of the electrical grid, which brings about the Smart Grid paradigm [10,28]. This kind of electrical grid provides a set of characteristics that allow a better use of energy, an increased control, an improvement of management adding real-time monitoring. They also lower the maintenance costs, help in the decision-making process and providing a better electric service, among other aspects. Moreover, Smart Grids must be auto-regenerative, able to support different types of anomalies in the system, give a certain degree of reliability and efficiency, while always having control of the entire network stages (Generation, Transport, Distribution and Client stage).

Currently, one of the most influencing problem is the so-called Peak Demand or Peak Load Problem [27]. The Peak Demand Problem consists in an overload generated by the simultaneous energy consumption of several devices connected

* Corresponding author at: Grupo de Investigación en Tecnologías Informáticas Avanzadas (GITIA), Facultad Regional Tucumán, Universidad Tecnológica Nacional, Rivadavia 1050, San Miguél de Tucumán, Tucumán, 4000, Argentina.
E-mail address: diego.lizondo@gitia.org (D. Lizondo).

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to the grid (in general Air Conditioning or Heating devices) in a relatively short period of time. This electric consumption reaches critical energy levels that severely affect distribution equipments. This problem causes different types of damages related to technical and operational issues, being sometimes irreversible or irreparable. The economic cost associated with repairing damages or replacing burnt or broken devices is high. Other collateral effects related to this problem are the inconveniences and discomfort caused to the consumers, gradually affecting the image of utility companies. Even in the case where no equipment is damaged, the difference between low and peak consumption forces utility companies to oversize several expensive aspects of the grid in order to cope with this demand.

The Peak Load problem is complex because it changes depending on the particular population and involves different kinds of actors and factors, and its effects cannot be entirely measured. To tackle this problem, some researches were conducted to avoid the peak using different viewpoints with techniques like Spinning Reserve [9] and Load Leveling [16], Peak Shaving [19,20] and Battery Storage [25]. Previous research related to the Peak Load Problem can be categorized in two approaches: top-down and bottom-up. The first mainly focuses on Generation and Transport stages, the second focuses on distribution and client stages. Our work is inspired by the second approach with the Demand-Side Management [23,30] and Demand Response techniques [21].

In this work, a heuristic algorithm based on the Artificial Immune System (AIS from now on) [14] is presented in order to address the peak demand problem. The proposed algorithm uses the dynamic and auto-regulation capacities of the AIS to control the energy consumption in a determined zone and time period. The algorithm controls the load in a determined spot in the grid called the Energy Supply Node (ESN), to avoid the possible damages of an overload. Moreover, the system provides a mechanism that allows the electric utility company to regulate and diminish the consumption in a given area, redirecting the energy to other uses or simply saving it. The algorithm features follow the guidelines set by the Smart Grid paradigm, in the sense that it is fault tolerant, distributed, autoregulated and self-controlled (features provided by AIS heuristic). Other algorithms found in the relevant literature are centralized, require human supervision, and/or require an expensive and complex communications infrastructure, but the proposed one requires minimal communication infrastructure when compared to a centralized system. This paper corresponds to a patent application, presented in No. 2016 (see Section 7).

The rest of the paper is organized as follows. In Section 2 the peak load problem is described followed by the mathematical formulation presented in Section 3. Section 4 describes the related works and the focus of this paper. Section 5 contains the main contribution of this article. In this section, the basic concepts of AIN are presented followed by the full description of the proposed AIN-PS Model. Finally, Section 6 contains the results and Section 7 presents our conclusions and future works.

2. Peak load problem

The electric emergency was declared as one of the major problems that should be addressed taking into account the efficiency and the environmental impact [33]. Also, most of the aspects that influence the energy consumption have regional validity, and the characteristics of the problem change depending on the scale, certain infrastructure, market conditions, or even political and socio-cultural aspects [3,15]. Additionally, thermo-controllable devices are commonly associated with the Peak Load problem, and its effects are more visible in countries with Tropical and Subtropical climates due to the utilization of a high number of air conditioning devices.

In the Tucumán province (Argentina), during the hot season, the average apparent temperature is about 35 °C with a maximum of 60 °C, and 40% of Humidity [18]. This scenario holds for over 80% of the time during this period. Consequently, the use of cooling devices is extremely high and their use increases every year. Furthermore, the houses and buildings in the province are usually not adequately insulated relying in a wide use of Air Conditioning devices to maintain a comfortable temperature. In fact, they are kept running for long periods of time for the heat does no drop considerably during the night. Peak hours or in our case “peak consumption hours” in the summer span up to four hours (from 1 p.m. to roughly to 5 p.m., o even more). It is a long period of time of high electric consumption in about two to four months a year.

As the installed capacity fails to meet the energy demand, there are periodical and partial denials of service, followed by blackouts covering large areas on extreme cases. This extreme peak consumption affects and reduces the lifespan of the nodes and equipments that provide the electric energy. In December 2015, the Argentine government in an official statement [7] decreed the energy emergency, highlighting that although the energy production is in good shape, but the distribution sector is severely affected by this situation.

This problem affects not only the social and economic aspects of several countries, but it also has an impact on global climate change: many works emphasize that Energy Management and Optimization are some of the most feasible and proactive approaches to climate change in the short and medium term according to section two of the Kyoto Protocol.[1] Even more, in the Paris Agreement[2] one of the main Energy Efficiency Targets is to achieve at least 27% increase in energy efficiency. Furthermore, the proposal of setting air conditioning devices to 25 °C (77° Fahrenheit) was evaluated by the ClimateLab,[3] and it estimates a global CO_2 emission saving of 194.16 Mt of CO_2. That amounts to an energy saving of about

[1] http://www.kyotoprotocol.com/.

[2] http://unfccc.int/paris_agreement/items/9485.php.

[3] http://climatecolab.org/contests/2016/industry/c/proposal/1329804.