New Renewable Energy Allocation Algorithms based on Bin Packing in a Smart Home

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Abstract: More and more home owners fit their homes with renewable energy sources. Thus, to capitalize this, they are willing to install intelligent energy management systems to try to reduce their energy bills, which requires optimal use of energy. To deal with this, this paper presents two energy management algorithms, all based on the principle of the bin packing problem. The proposed solutions are built on prioritizing the use of renewable energy produced locally over energy provided by the main grid. A well detailed simulation was carried out to highlight the contribution of the implementation of this solution in a smart home located in Casablanca, Morocco, whose energy needs are from a daily approximation of the habits of the city residents. Moreover, a comparison between the two algorithms was made to showcase the benefits of each, and their difference.

1 INTRODUCTION

Day after day, the traditional grid undergoes major transformations which are observable at the production sites, the consumption point, and of course, along the whole network of transmission/distribution lines. There is no point of the grid that is untouched by the integration of the ICT in the grid conversion into smart grid (Kempener, Komor and Hock, 2013).

As power energy price has been both increasing through years and requested by more consumers, energy good management is of absolute necessity. Therefore sustained works need to be done in this direction: find new ways to optimize at the same time the production, the transport and the consumption of the power energy.

The incorporation of smart items such as smart meters, actuators, middleware in the grid lead us to two major interacting components: a smart grid and a smart load. Hence the need to develop good strategies of energy allocation either between the two components, or only at the smart load. This because the smart load has sometimes a production unit of electric energy (solar, wind …), which makes him a small smart grid apart (Considine and Cox, 2009).

This paper is all about these smart loads, especially smart homes, because the third sector in energy consumption, which includes households, is the one that consumes the most electric energy, especially in Morocco (Jaouhari, et al., 2013), as elsewhere around the world. This prompted us to seek a solution to maximize the use of renewable energy produced on site. The renewable energy produced will be called local energy for the rest of the paper.

Recent research topics point out some solutions which have already been used in strategies of energy allocation in smart homes. Guo, et al. (2012) and Wu, et al. (2013) apprehend this problem as stochastic optimisation by minimizing the energy cost based on dynamic pricing. Samadi, Schober and Wong (2012) propose the use of Vickrey-Clarke-Groves (VCG) mechanism to maximize the social welfare where the implemented solution of pricing can benefit both users and utility companies. Mishra, et al. (2012) introduce a way to minimize the electric bill with the help of storage components (batteries) as controller of energy consumption. Alamdar (2013) ushers us to a solution based on strip packing. It consists in finding a schedule that minimizes the peak load.

In this paper we focus on a different way to optimize the use of energy, not by minimizing the electric bill directly, but rather maximizing the use of the local energy. Thence, the combination on an optimum use of local energy and the battery ensures a low dependence opposite the main grid, and consequently a reduction of the electricity bill. The

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proposed solution is based on the bin packing algorithms.

The bin packing problem falls within the operations research and combinatorial optimization. It is about finding the most economical storage possible for a set of items in boxes (Scribe, Watson and Shuchi, 2007). These algorithms, applied to a smart home, turns out to be an interesting solution in energy management.

To address this issue, this paper is organized as the following: In the next section we present a smart home as a working environment. In section 3 we formulate the energy allocation problem as a bin packing problem. Then in section 4 we describe the proposed algorithms that address our issue, and present some results with a certain number of figures computed with the Matlab software (Mathworks, 2015). We conclude in section 5.

2 SYSTEM MODEL

We consider a smart power environment with middle-class residential house, consisting of four blocks: the living room, two bedrooms, a bathroom and a kitchen, as shown on Figure 3.

2.1 The Energy Production

Local energy comes from the exposure of solar panels to the sun, during the day. We assume that our house features two solar panels whose power peak is $1Kw_p$ each, within standard conditions. So the energy produced equals to 1 kWh in the same condition (Lewis and Crabtree, 2005). For a real installation, the energy produced is generally much less than what would be produced under standard conditions. It essentially depends on three factors: the daily global radiation, the solar panels position and their temperature (Duffie and Beckman, 1980).

To obtain an estimate of the daily production of local energy we used a complete photovoltaic simulating software (PVSyst, 2015), then chose the geographical position of Casablanca (33°65'N 07°26'W).

The solar irradiance on Figure 1, at that position computed with PVsyst allow us to estimate the power output of our house per hour.

The Figure 2 points out that the local energy production follows a normal distribution of 3,57Kwh as mean average and 25% as SD, per day; where between 0am and 6am, 5pm and midnight the contribution solar energy tends to zero.

The intended time cycle for the system's operation is divided in 24 time slots, regarding hours within a full day (day and night).

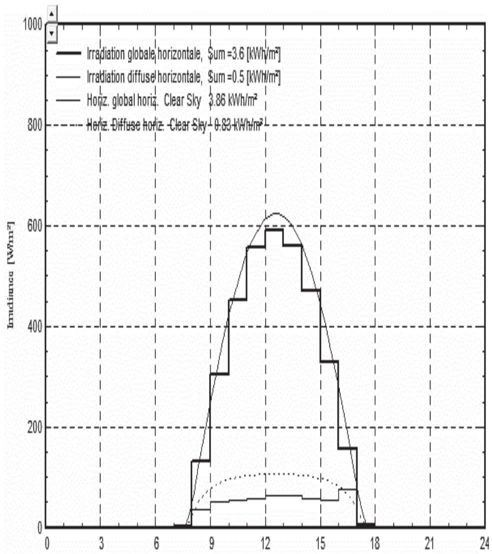

Figure 1: PvSyst diurnal predicted hourly solar radiation for Casablanca.

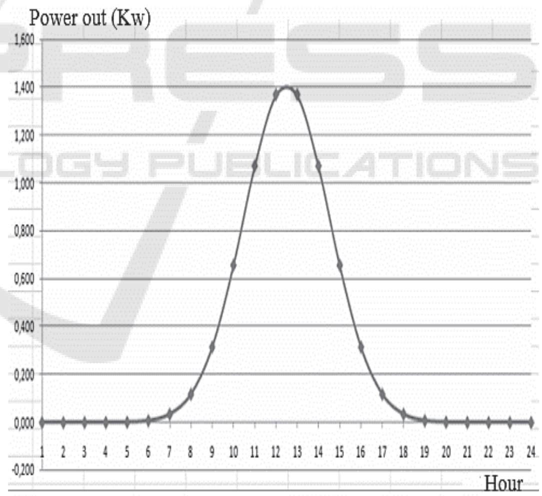

Figure 2: Electric power produced during a day.

2.2 The Energy Consumption

Our house is equipped with typical household appliances (Laconde, 2015) gathered in table 1. It must be recalled that this house is divided into four blocks, which is an arbitrary choice but helps to implement our solution based on bin packing; i.e., the proposed energy allocation solution may, thereafter, be either generalized (each block being an apartment in a building) or refined (each block being a smart plug in the house).

The consumption of each block takes the form of a vector of 24 time slots, each slot corresponding to an hour of a day. By adding the consumption of each connected device during the same time slice, total hourly energy consumption of the whole house is obtained.

The calculation of different energy consumption in different blocks has been done based on an example of a middle class Moroccan family, living in Casablanca. Data in Figure 4 do not represent all the middle class Moroccan families. They are debatable but not wrong at all. In any case, their approximation does not alters the results of the solution proposed in this paper, since it is an adaptable solution which works in any scenario.

2.3 Hypothesis on Batteries

We assume that our smart home is equipped with a 12V, 150Ah battery; and has two operating modes:

The day mode is restricted from 7am to 6pm, during which the battery is a receiver and loads up to its maximum level; and the night mode, for the remaining hours of the day, where there's a lack of solar energy. The battery acts as a secondary voltage source to local energy.

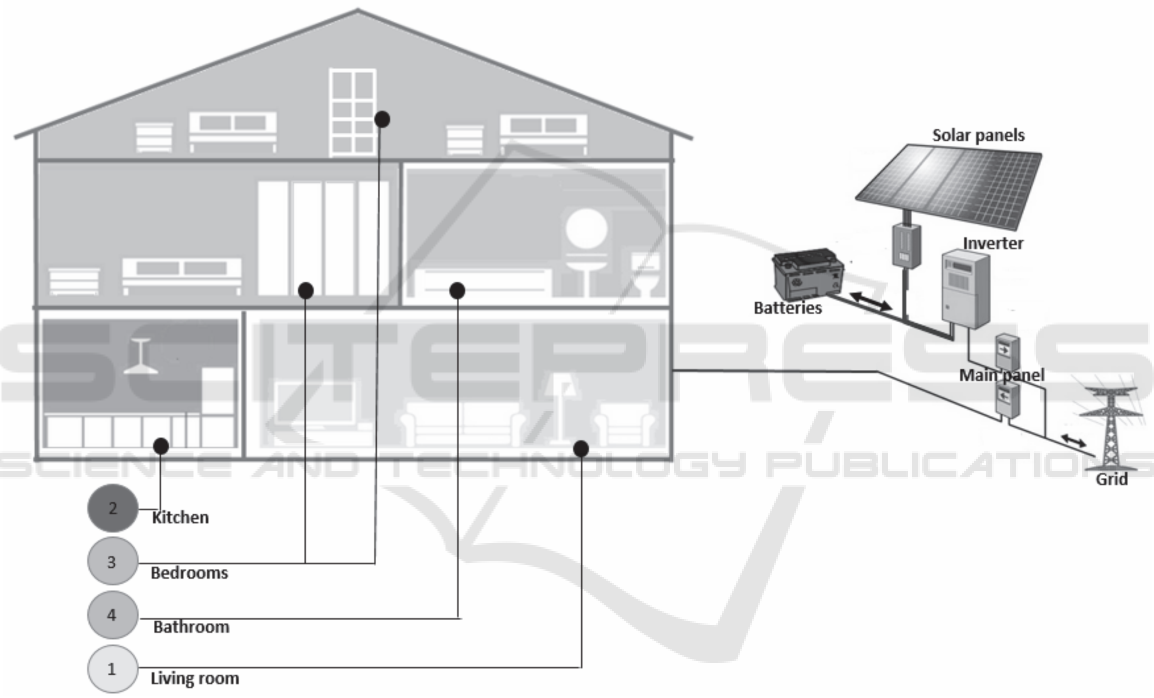

Figure 3: Smart home, divided into four blocks.

Table 1: List of appliances used in the home and their mean electric average power.

Appliances in the living room	**Number**	**Average power**	**Appliances in bedrooms**	**Number**	**Average power**
Lamp	3	10w	lamp	**2**	**20w**
TV LCD	1	200w	Computer	**2**	**60w**
Wi-Fi router	1	5w	Alarm clock	**2**	**20w**
Heating	1	500w	Smartphone	**4**	**20w**
Appliances in bathroom	**Number**	**Average power**	**Appliances in the kitchen**	**Number**	**Average power**
Lamp	1	10w	lamp	2	20w
Hair dryer	1	600w	Refrigerator	1	150w
Electric shaver	1	20w	Microwave oven	1	800w

3 PROBLEM FORMULATION

As the problem in this paper is to find an efficient way to allocate energy in a smart home, the proposed solution, based on the bin packing problem, appears to be one of the best ways of solving this problem.

3.1 The Principle of Bin Packing

The bin packing problem can be described as follows: having n items and n bins with:

w_j = weight of item j

c = capacity of each bin

Must assign each item in a bin so the total weight of the items in each bin does not exceed c and the number of bins used is the minimum.

Mathematically this is written as follow:

Minimize $z = \sum_{i=1}^{n} y_i$

Subjected to

$$\sum_{j=1}^{n} w_j x_{ij} \leq c y_i \quad i \in N = \{1, \dots, n\}$$

$$\sum_{i=1}^{n} x_{ij} = 1 \quad j \in N$$

Where $y_i = 0 \text{ or } 1 \quad i \in N$

$x_{ij} = 0 \text{ or } 1 \quad i \in N, j \in N$

3.2 Situation Scenario

We wish to apply the bin packing algorithms in electrical engineering, specifically to our problem, in order to optimize the power allocation. Our goal is to reduce the use of the main grid energy to the benefit of the use of local energy.

By analogy to the concepts of bin packing, the bins correspond to both the local energy and the main grid energy. The objects to be classified correspond to different blocks of the house.

Among the bin packing algorithms, Next Fit, First Fit, Best Fit, Next Fit Decreasing, First Fit Decreasing, Best Fit Decreasing,… proposed in the literature (Hayek, 2006) to solve the packing problem, we selected two: the first fit decreasing for its low execution time, and best fit because of its capacity of using less bins for a maximum items (Lodi, 2000).

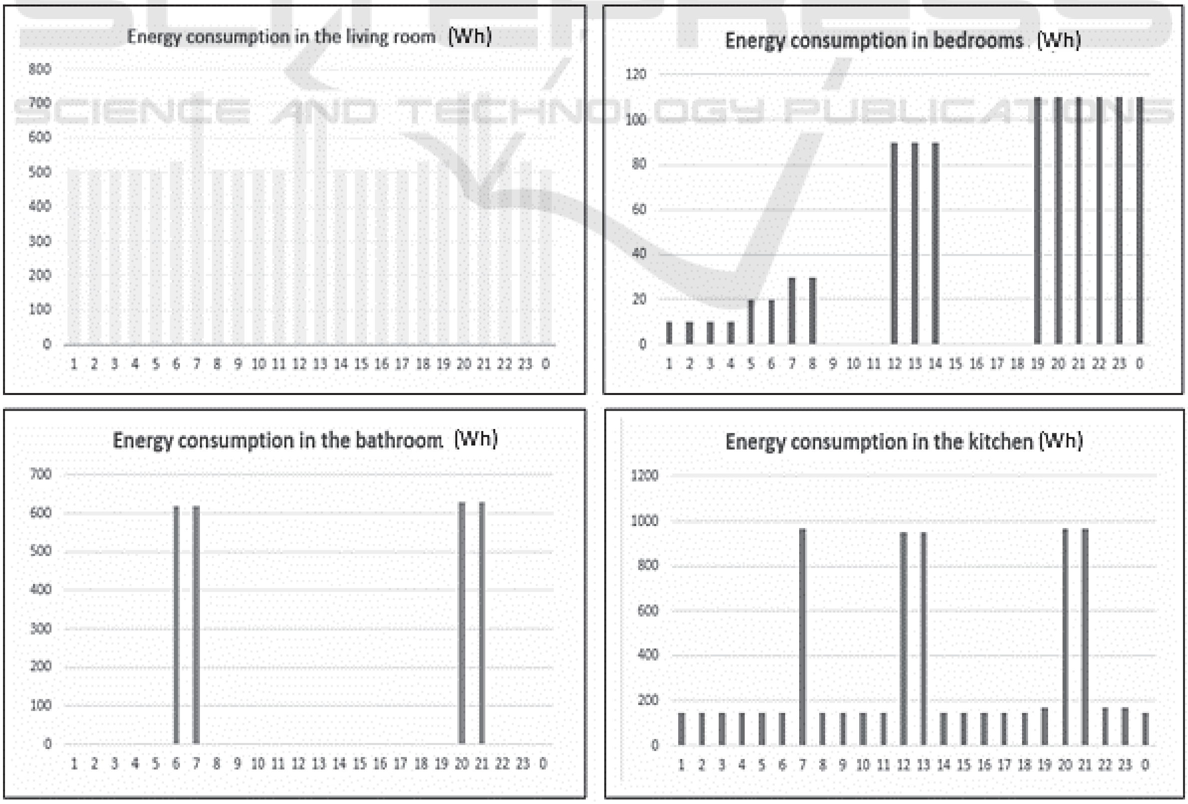

Figure 4: Energy Consumption of different blocks in a day.

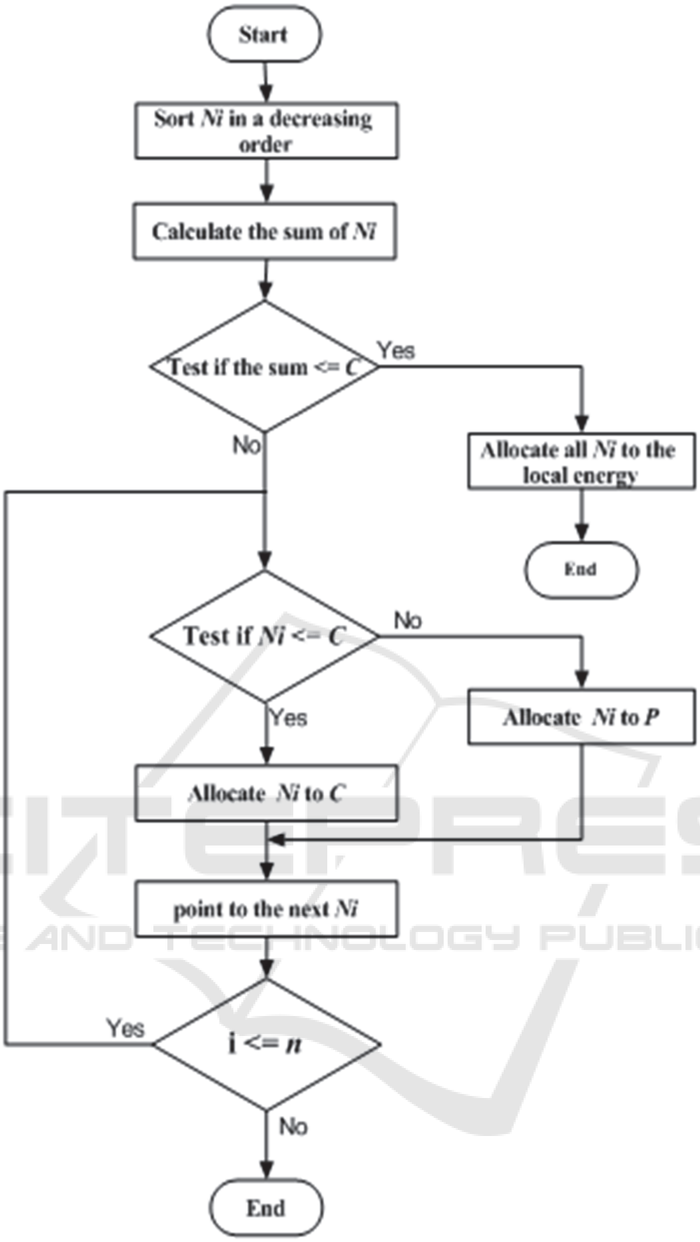

Figure 5: Flowchart of the First Fit Decreasing energy allocation algorithm.

4 THE PROPOSED ALGORITHMS, RESULTS & ANALYSIS

Through the rest of the paper, following variables represent respectively:

Ni = blocks' energy needs, $i \in [1, \ldots, n = 4]$
S = a sum of a certain number of Ni
B = capacity of the battery
C = local energy remaining amount
P = *main grid* energy

4.1 First Fit Decreasing Algorithm

With this bin packing algorithm, the items are ordered into their descending order, and then in this order the next item is always placed into the first bin, where it fits. For our problem, the proposed solution acts like illustrated on Figure 6:

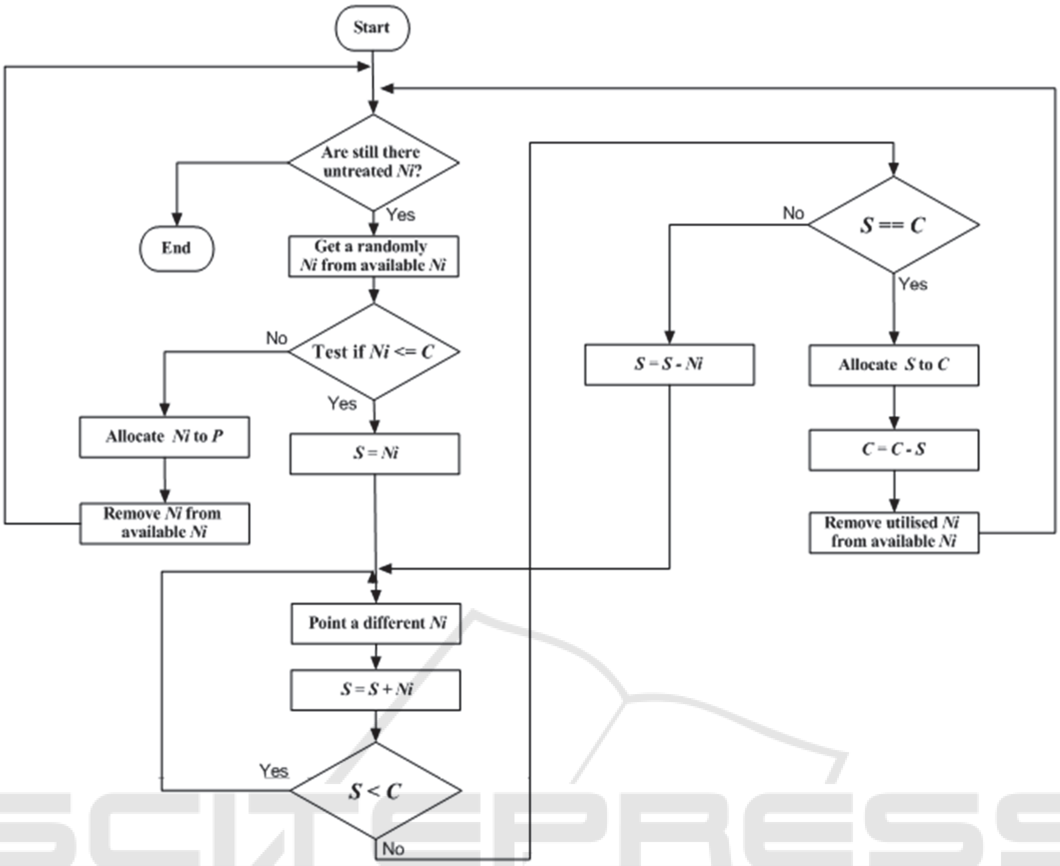

Figure 6: Flowchart of the Best Fit energy allocation algorithm.

4.2 Best Fit Algorithm

This algorithm scans all the boxes to find a best fit of free available capacity for the requested item size. The situation is more complicated, as the notion of the "following bin" is not clear, in fact a careful choice is needed. The proposed algorithm follows these steps presented in Figure 6.

4.3 Results & Analysis

Local energy comes in from 7am to 6pm. The interpretation of the Figure 7 shows us that there is a very high contribution of energy around noon. This would either reduce the peak load in case there is one, or indicate that some household tasks could be scheduled in case there is exceeding local energy.

Nevertheless, during the hours when there is not much local energy (early morning and late afternoon), we can see that the Best Fit (green) stands out from the First Fist (brown) by allocating more efficiently renewable energy to the consuming blocks (the remanent local energy from First fit is stored in the battery for to be used during the night). And this is highlighted in the table 2, where BF stands for Best Fit energy usage, and FFD for First Fit Decreasing energy usage.

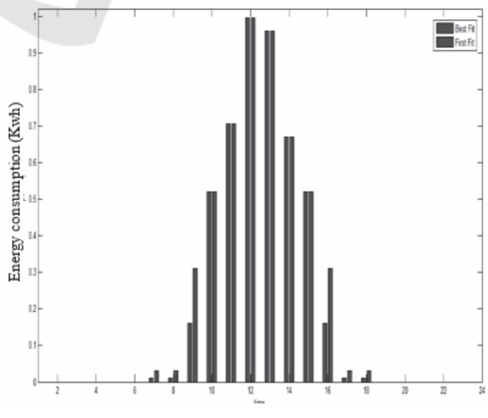

Figure 7: Comparison between the Best Fit and the First Fit Decreasing energy allocation algorithm.

Table 2: Local energy gains.

hour	Gain (%)= (BF/FFD)*100
6 am	0
7 am	66.6
8 am	66.6
9 am	48.38
10 am	0
11 am	0
12 am	0
1 pm	0
2 pm	0
3 pm	0
4 pm	48.3
5 pm	66.6
6 pm	66.6

5 CONCLUSIONS

Driven by a desire of finding a strategy to allocate energy within a smart home, the work done in this paper aimed to develop a solution that would optimize the consumption of renewable energy produced locally onsite.

We provided two algorithms, one based on the First Fit Decreasing and the other on the Best Fit, all based on the principle of the bin packing. Matlab simulations of these algorithms have demonstrated a clear fulfilment in their way to manage the energy, by promoting the consumption of local energy over the main grid energy. The first gives better satisfaction in terms of execution time, the second gives more satisfaction in terms of energy performance allocation.

The only questionable problem is that the consumption data we used is based on observation of one middle class individual house in Casablanca, over a period of a few days. A thorough study on the consumption of households in Morocco to work with real data would have been an asset to our work. That is why in the work ahead, measurements made on several houses are planned to establish a real energy consumption profile of a typical Moroccan house.

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