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A case study of solar technologies adoption: criteria for BIPV integration in sensitive built environment

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Abstract

Solar Photovoltaics is one of the core technologies for a paradigm shift of our electric infrastructure towards distributed generation. In 2011 Italy became the first world market; however, Germany has even the primacy of accumulated power. The installed capacity amounted to 10.000 MW according to data of Italian Manager of Energy Services (GSE) against 1.000 MW in 2010 and 3.000 the beginning of 2011. The projections of GSE include the achievement of the 12.000 MW by the end of the year with more than 350.000 running plants. In a nearly mature market, cost related issues and technical difficulties are encountered in particular in the successful integration within a sensitive and consolidated built environment. The research presented aims to investigate the possible results of an effective use of Building Integrated Photovoltaics (BIPV), choosing existing buildings in the city of Bellinzona (Canton Ticino, CH) as case studies. Bellinzona presents similar characteristics to small Northern Italian cities in terms of built environment characteristic and climate conditions. The theoretical framework for the analysis is the one proposed initially for low energy and nearly net zero energy buildings (NZEB). Although this type of analysis has been developed, in particular, for building with high penetration of renewable energy sources generation (up to 100% of the energy consumed), it seems worth investigating the dynamic interaction of building energy demand, on-site generation and grid with similar tools, because of the necessity of achieving low energy demand also in retrofitted existing buildings in a near future.

Keywords: BIPV; built environment; load matching index; grid interaction index

1. Introduction

According to the latest report of the European Photovoltaic Industry Association (EPIA) [1], Italy can achieve the "grid parity" in 2013 as a record in European countries that will reach it by 2020, considering

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the growth of the price of electricity from renewable sources. The study of EPIA also foresees, by 2020, a further potential for reducing the cost of photovoltaic by 50% (with a range that goes from 36 to 51% depending on market segment) with energy production cost ranging, respectively, from 0,16 to 0,35 €/kWh in 2010 and from 0,08 to 0,18 €/kWh in 2020, depending on the solar irradiation of the site and technologies considered. A recent research performed by the Lawrence Berkeley National Laboratory (LBNL) [2] show a reduction of the 7% of the cost for PV systems in 2010 and 11% in the first half of 2011 resulting from lower prices of PV modules and a decrease of about 18% of the costs due to inverters, installation and marketing, registered between 2009 and 2010.

Nomenclature

f_{load}	load matching index
f_{grid}	grid interaction index
g	electric power generation
G	electric power generation weighted
i	index of time step in the time sample
j	index of time sample
m	number of time steps in one sample
min	minimum function
max	maximum function
n	number of time samples
l	electric load
L	electric load weighted
STD	standard deviation
w	weighting factor

In 2011, Italy became the first world market for PV, despite Germany maintains the primacy of accumulated power. The installed capacity amounted to 10.000 MW according to data of Italian Manager of Electric Energy Services (GSE) [3] against 1.000 MW in 2010 and 3.000 the beginning of 2011. The projections of GSE include the achievement of the 12.000 MW by the end of the year with more than 350.000 running plants. Market growth is surely a result of the favorable incentive scheme called “Conto Energia”, which, however, in June of 2011 envisaged the reduction tariffs by around 20%. A progressive reduction of incentives is necessary to stimulate the competitiveness in a nearly mature market that is entering a phase of stability, after the initial phase where interventions were most designed to fit the more advantageous incentive scheme [4].

As highlighted by the statistics, the number of solar installations in Italy and in other European countries is constantly growing. This is due, on the one hand, to the instability of the fossil fuel prices, on the other hand, to the increasing involvement of consumers in energy saving and renewable energy initiatives. In order to regulate the adoption of renewable energy technologies in buildings and to define a suitable design approach when using solar technologies in a sensitive urban environment (where architectural, historical or cultural value is considerable), a multidisciplinary project was launched in

Canton Ticino, Switzerland (Italian language part) in order to define a set of criteria and recommendations for such sensible areas.

The focus of the project is put, first of all, on two main aspects: innovative products and effective practices of integration in the building envelope.

The tools and methodology developed within the project are expected to help both consumers and professionals in the choice of the most appropriate solutions but also Public Body (municipality) in the preparation of guidelines for solar system integration in the built environment and also in the preparation of directives and standards.

2. Methodology and criteria for integration

In order to prevent an indiscriminate and uncontrolled use of solar technologies and, at the same time, to invest economic and space resources in the most effective possible way, it is necessary to find a proper balance, or compromise, between technical and aesthetic requirements.

In the first part of the research technical and architectural guidelines have been developed for the integration of active solar technologies (photovoltaic and solar thermal) in buildings, with a specific attention to historical constructions. A specific check-list [5] has been developed for planners and architects (but also building owners) to enable easier decision-making process in the early design phases.

The existing housing stock, both in Switzerland and in northern Italy, is very heterogeneous. Constructions have to fulfill not only different needs but can be categorized also according to building techniques, year of construction, materials, components, representative status and, of course, architectural quality.

While there exists clearly a technical possibility for the integration of PV and solar thermal on a building façade, most of the potential is intrinsically related to intervention in the roof, especially in sensitive urban environment. The roof typologies identified are listed in the following table.

Additionally, in order to enhance the overall architectural design quality and durability of solar installations, it is necessary to define, first of all, the formal constraints which can negatively affect the project, and then to identify appropriate solutions. Six criteria, focusing on shape and emplacement of the solar panels are considered and described in the following table.

Table 1. Roof typologies identified

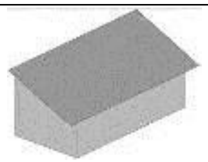
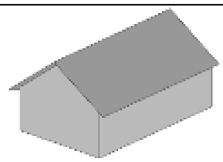
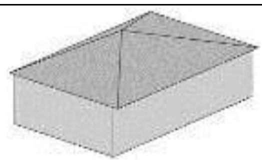
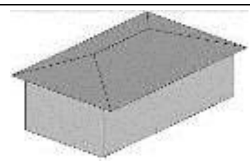
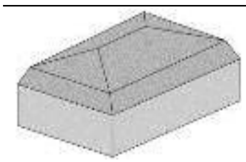
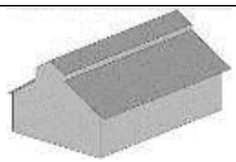
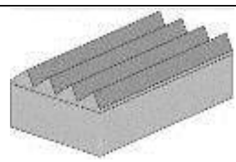
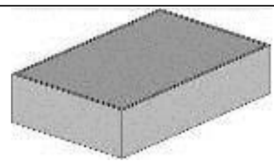
Skillion roof	Gable roof	Pyramidal hip roof	Simple hip roof
			
Mansard roof	Monitor roof	Sow-tooth roof	Flat roof
			

Table 2. Criteria for the overall design quality and durability of solar installations

Criteria	Description
Co-planarity	Solar system has to be installed on the same plane of the building surface.
Respect of the lines	System has to respect the lines which provide the outline of the construction, particularly in the upper part
Shape and grouping	Random solar installation has to be avoided
Grouping	Modules have to be grouped together in an ordered way
Accuracy	Solar panels added to or integrated into a building must be perfectly connected or inserted into the construction element
Visibility	The decision to install a solar system on a (protected or not) building must consider the environment in which it is located

2.1. Requirement for products integration

High architectural design quality for BIPV [6] is becoming progressively a necessity; today a number of innovative and advanced products for building integration that can be used in sensitive built environment are present on the market. These products can be used, for example, in historical centers and can be acceptable also in naturalistic contexts where buildings need energy supply. They are characterized by different technology, performance, morphology and can constitute high quality assembled building envelope components. Considering also the indications contained in the Fourth edition of the Italian "Conto Energia" we can consider as BIPV the products that effectively replace building envelope components (an exhaustive BIPV product database can be found at www.bipv.ch).

The main aim of this check-list is to develop consciousness in public decision-makers to identify ways to introduce PV systems in accordance with users' acceptance and cultural and architectural heritage. With respect to the elements already described, such as roof typologies and criteria, further recommendations are added, related in particular to: cover of the construction surface; multi-functionality; application; aesthetics, sizing.

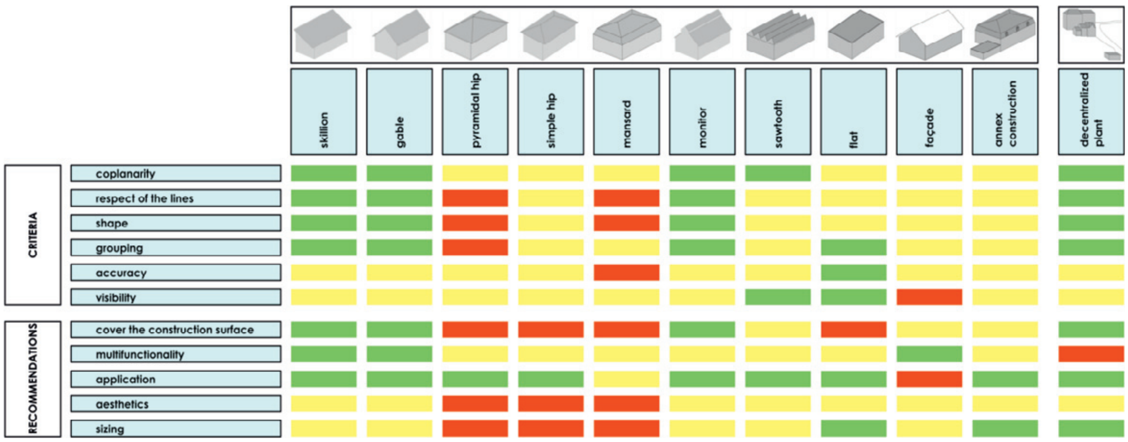


Fig. 1. Criteria and recommendations proposed for different roof configurations

Where:

(green)	The criteria / recommendations are easily respected. A good planning is always mandatory.
(yellow)	The criteria / recommendations can be respected without difficulty if the installation is taken into account during the very first stages of the planning process. A thorough approach is also needed (check for: more suitable technology, constructive and technical features of the building, architectural and aesthetical characteristics, type and quality of the surrounding, visibility).
(red)	The criteria / recommendations can be respected but it is necessary to carefully consider certain aspects (see the specific criteria / recommendation page for more information).

3. The case study

The design of efficient BIPV systems in the urban environment starts from the categorization of the typologies of surfaces and necessitates criteria to accomplish high quality integration. In this way it is possible to evaluate the solar potential, estimating energy production and the possible integration in district-scale plants synergies to feed the city with renewable energy sources [7,8]. It is very important for Municipalities and Public decision-makers to have reports and pilot cases in order to explain criteria to promote solar integration. The market, on the other hand, is receptive to needs for products to satisfy requirements that can be subject to regulations and are being developed by the R & D Institutions to fill the gap between the design and decision-making levels.

The buildings analyzed are part of the general case study, represented by the city of Bellinzona. In 2010 the historical centre of Bellinzona [5] was analyzed together with its near-by surroundings in order to assess the solar potential of the chosen urban area. This evaluation allowed the verification of the criteria and recommendations explained before. Bellinzona is the administrative capital of the canton Ticino in Switzerland and has a population of about 18.000 unit. The area of the city is about 19 km^2. The city of Bellinzona is completely surrounded by mountains. This naturalistic configuration has an important effect when planning solar installations. The shadows generated by the surrounding have to be added to the ones created by the urban context.

The planimetry of the centre of Bellinzona shows a very packed core, typical for a medieval village, while the surroundings are characterized by a lower degree of density. This means that constructions in the historical centre will mostly overshadow each other, especially the façades. In the specific context, façades are much better preserved compared to the covering elements and adding or integrating photovoltaic and/or solar thermal panel on them will consequently altered an element which is perfectly functional and architecturally valid. Moreover, in densely built areas, as in this case, façades are the elements of a building which suffer more the shadowing effect caused by the surroundings constructions.

The visibility of the area differs greatly depending on the point of view; from the street level roofs are only partially visible. Of course from a higher location (the castle or the surrounding hills) the landscape of roofs is much more observable.

After the analysis of the urban space only six building were chosen in first instance to be suitable for PV installation. The six specific “objects” where chosen as they represent samples of the housing stock that characterizes the old town of Bellinzona and its immediate neighborhood.

The refurbishment of the building heritage and installation of new technologies, such as the already cited solar thermal and photovoltaic systems, must be compatible with landscape, environmental and cultural values. The federal, cantonal and communal administrations cannot take the risk of being unprepared when facing new technologies and new materials. A greater dialogue between the different stakeholders and disciplines that relate to historical heritage is necessary.

Table 3. Criteria for the overall design quality and durability of solar installations

Building	Type of building	Year of construction	Orientation of roof
1. Government building Scerri	Administrative building	1970	Flat
2. Government offices	Administrative building	1960	Flat
3. Palazzo delle Orsoline	Administrative building (originally a convent)	<1900	Tilted
4. Salita San Michele 3	Residential building	1950	Tilted (SW)
5. Salita San Michele 4	Residential building	1900	Tilted (SW)
6. Banca Stato Headquarters	Administrative building (originally a convent)	<1900	Tilted (S)

4. Analysis and numerical results

In this section the results of the numeric analysis performed for two representative buildings is described. The analysis involves in particular the comparison of electric load data and PV power generation for two selected building and the associate load matching index and grid interaction index [9], respectively assuming the point of view of the end-user and of the electric power system (grid). The calculation of such indexes can be done for different time sample: hours, days, months. The methodology used is extensively described in [10,11]. The buildings selected are number 2, Government offices (administrative building) and Salita San Michele 4 (residential building).

We can express the overall energy balance of a building with respect to the exchange with the grid with the following expression.

$$\sum_{i=1}^{m} g_i - \sum_{i=1}^{m} l_i = g_j - l_j \tag{1}$$

The values of g_i and l_j, respectively generation and load of the right hand side and the left hand side coincide if we start from hourly values and we consider hourly sample. For every time step the minimum is calculated with the following expression.

$$f_{load,j} = \min\left[1, \frac{g_j}{l_j}\right] \cdot 100 \tag{2}$$

The average value of load matching index over a year with a certain sample period is calculated as follows.

$$f_{load} = \frac{1}{n} \cdot \sum_{j=1}^{n} \min\left[1, \frac{g_j}{l_j}\right] \cdot 100 \tag{3}$$

The value of grid interaction index for every time sample is calculated as follows.

$$f_{grid,j} = \frac{g_j - l_j}{\left|\max\left[g_j - l_j\right]\right|} \tag{4}$$

The maximum of the modulus at the denominator is calculated among then different time samples over the year, after that the standard deviation of the previous indicator is calculated with different time samples (over the year also in this case).

$$f_{grid,j} = STD\left[\frac{g_j - l_j}{\left|\max\left[g_j - l_j\right]\right|}\right] \tag{5}$$

The electric load considered for the two buildings are appliances and plug load and the values obtained are reported in Fig. 2, 3, 4, 5.

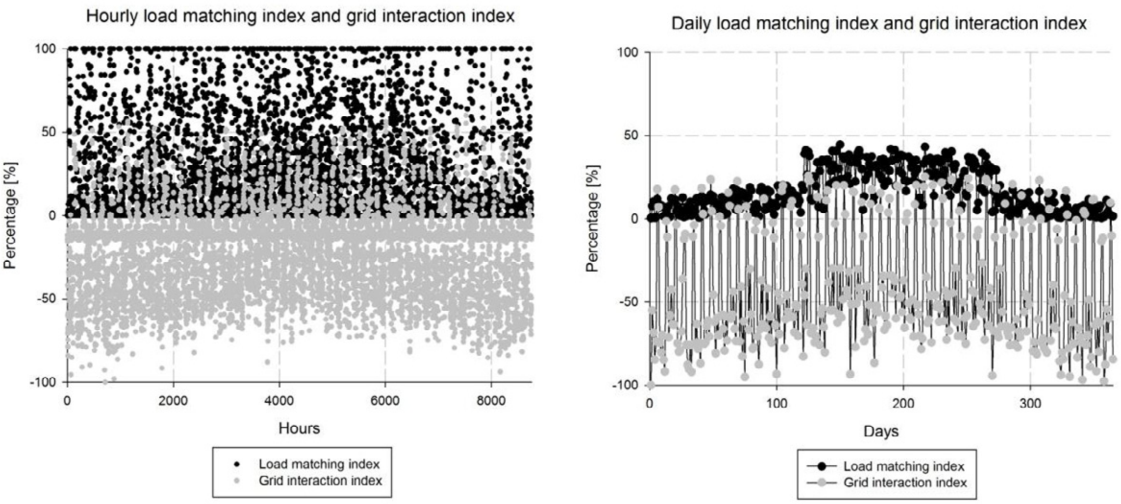


Fig. 2. Load matching index and grid interaction index for hourly and daily time intervals for the administrative building

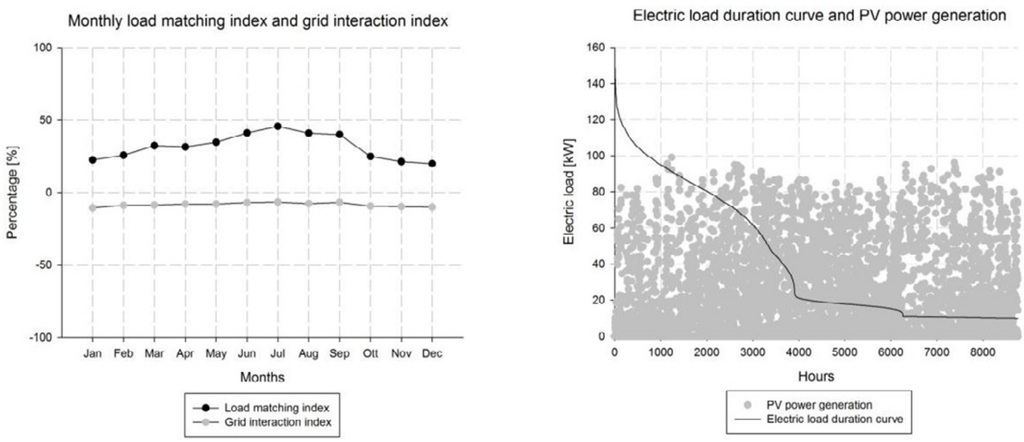


Fig. 3. Load matching index and grid interaction index for monthly time intervals and electric duration curve with respect to PV power generation for the administrative building

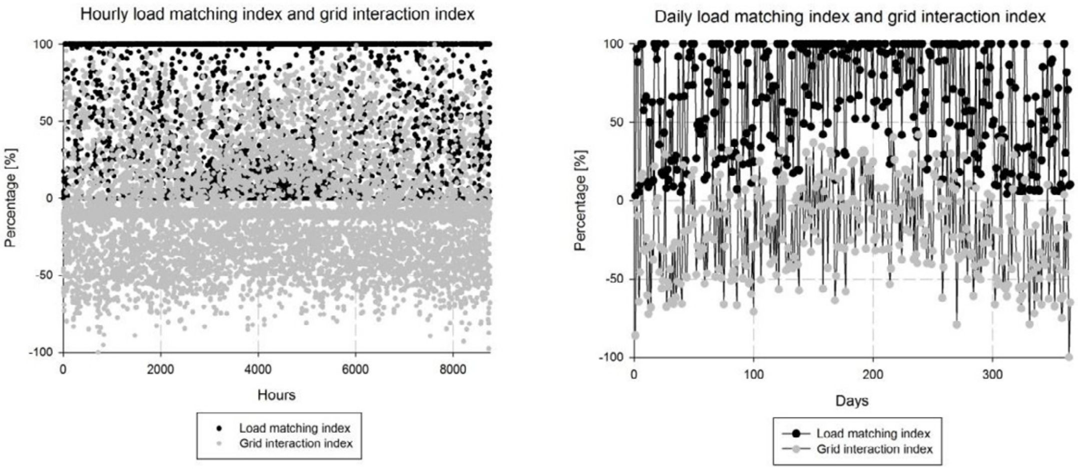


Fig. 4. Load matching index and grid interaction index for hourly and daily time intervals for the residential building

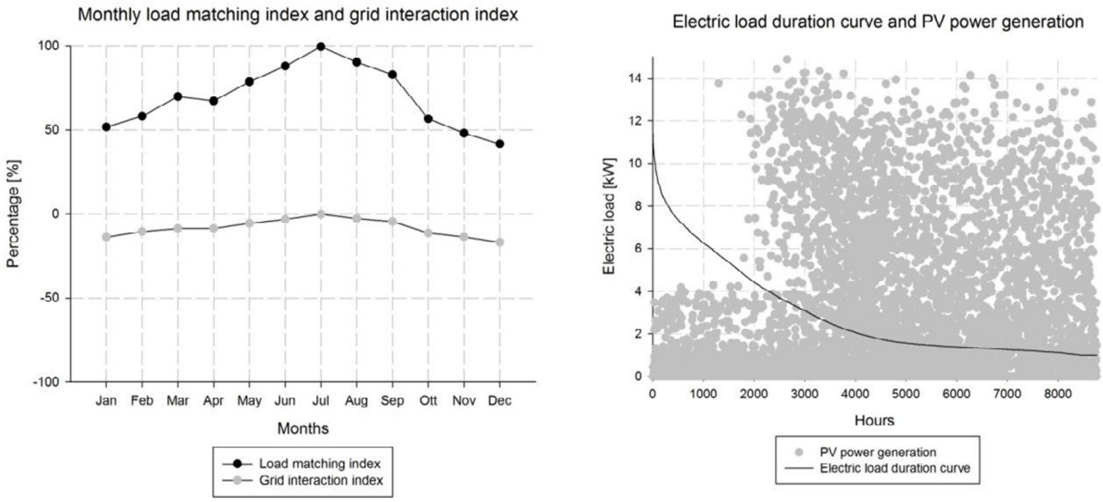


Fig. 5. Load matching index and grid interaction index for monthly time intervals and electric duration curve with respect to PV power generation for the residential building

Table 4. Average load interaction index and standard deviation of grid interaction index for the administrative building

Indicator	Time resolution		
	Monthly (%)	Daily (%)	Hourly (%)
Load matching index	31,7	40,7	22,9
Grid interaction index	1,32	34,4	23,3

Starting from the whole set of data, the average value of load matching index and the standard deviation of the grid interaction index, calculated according to (3) and (5), are presented for both buildings and the three different time samples (monthly, daily, hourly) in the following tables.

Table 5. Average load matching index and standard deviation of grid interaction index for the residential building

Indicator	Time resolution		
	Monthly (%)	Daily (%)	Hourly (%)
Load matching index	69,4	63,5	37,4
Grid interaction index	5,2	28,8	34,2

The penetration of PV energy generation with respect to the total electric energy demand of the two buildings considered is around 32% for the administrative building and 69% for the residential building and although the values obtained are not as high as the ones achieved by very low energy buildings it is nonetheless clear from the graphs presented before that an effective of a considerable amount of PV can determined continuous variation of the operational pattern of the grid.

As proposed in [10], load and generation values must be appropriately weighted, because the operation pattern of the energy infrastructures to which building are connected must be able to deal properly with fluctuations. The formula to be employed is the following.

$$\sum_{i=1}^{m} g_i w_{g,i} - \sum_{i=1}^{m} l_i w_{l,i} = G - L \tag{6}$$

Based on the variability of this coefficient, different optimization strategies will have to be determined based on the specific project [12], thus creating more appropriate and specific solutions, within the emerging framework of the smart grid [13,14].

5. Conclusions

The paper shows a research aimed at identifying criteria and methodologies for the successful adoption of building integrated solar technologies in a sensitive urban environment, with a particular emphasis on PV. The whole research work involved primarily the identification of technologies, criteria for pre-design and, by the end, a verification of the behaviour with a methodological framework consistent with the most recent calculation methodologies for low energy and nets zero energy buildings.

The building envelope becomes really important as it provides the necessary surface for the installation of the solar systems. In the near future we will see a strong diffusion of integrated solar system in the build environment, both in new and existing buildings (which represent the largest part of the building stock). Their diffusion will lead to a greater acceptability, even in city centres, as it happened for other technological innovations or for contemporary architecture.

Although the buildings considered are existing building it must be pointed out that, in the perspective of existing building stock refurbishment in the next years, using a similar methodology would be a secure incentive to the design of more efficient retrofitted buildings.

At European level the Energy Performance Building Directive recast, stress the importance of serious technical intervention in existing building stock. The calculation methodology presented in the last section, based on the balance of energy fluxes on a certain boundary, can be employed also for types of analysis in which electricity is not the only energy vector considered, and the boundary is not a single but rather a cluster of buildings or a district. By expanding the dimension of the problem the difficulty in the resolution increases but, however, more technological options become available.

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