Comparison of Contracts in Vehicle-to-Load to Benefit Both Retailers and Electric Bus Operators

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***Abstract*—Price fluctuations in the electricity market are becoming a major risk for retailers, and appropriate retail contracts with customers who have controllable demand-side equipment are becoming increasingly important. The aim of this paper is to identify a suitable contract that benefits both the retailer and the electric bus operator to promote Vehicle-to-Load as demand response. The electric bus operator optimizes the charging/discharging operations in various retail contracts, and the characteristics of the revenue for the retailer and the cost of the electric bus operator are analyzed in each case. By optimizing the charging/discharging operations of the electric bus with various retail prices in mixed-integer programming, it is possible to benefit both the retailer and the electric bus operator. The result shows that the two-step price for stimulating demand is found to be the best in terms of appropriate risk allocation between the retailer and the electric bus operator.**

***Index Terms*—Electricity Market, Electric Bus, Vehicle-to-Load, Demand Response, Retail Contract**

I. Introduction

The electricity market provides a risk for retailers with price fluctuations [1]. The appropriate retail contracts with customers who have controllable demand-side equipment are becoming increasingly important. As demand-side equipment, electric vehicles that are used as Vehicle-to-Grid is getting attention. In particular, electric buses are expected to be easier to make the charging/discharging operations than other types of electric vehicles, since they have fixed routes and schedules.

More than $20\,\%$ of all global carbon dioxide emissions in 2021 were from the transportation sector [2] and the introduction of electric buses can help to use more renewable energies in the transportation sector [3]. The use of Vehicle-to-Grid is expected to enter the electricity market for grid stabilization such as demand response and frequency regulation [4], [5], and be used as an emergency power source in case of disaster [6]. To promote demand response of the consumers using electric vehicles, the real-time retail price that follows the market price is introduced in several studies [3], [7]–[9]. Though the real-time retail price can promote demand response at the most, it can make the risk of the cost of the consumers larger because of the difficulty of following the price fluctuation completely. To make the risk of the cost of the consumers smaller, time of use pricing in that the electricity cost of charging and discharging changes gradually depending on the time of day is also introduced [10].

Although several approaches have been developed to utilize electric vehicles as Vehicle-to-Load for demand response, the retail price design to benefit both the retailer and the electric bus operator has been overlooked in pre-existing approaches. The aim of this paper is to identify a suitable contract to promote Vehicle-to-Load as demand response that benefits both the retailer and the electric bus operator with the optimizing charging/discharging operations of the electric buses. The contributions of this paper are

- C1) to optimize the charging/discharging operations with consideration of the electric bus schedule, and
- C2) to compare several types of retail contracts to benefit both the retailer and the electric bus operator.

Through the retail price setting and the strategic charging/discharging operation of the electric bus, positive outcomes are anticipated for both of them. In this paper, the characteristics of the revenue for the retailer and the cost of the electric bus operator are analyzed when they enter into retail contracts in various patterns, and the electric bus operator optimizes charging/discharging operations in each case. As patterns of retail contracts, the following cases are considered: (a) fixed price, (b) two-step price for stimulating demand, (c) two-step price for suppressing demand, (d) three-step price, (e) real-time price.

The outline is as follows. In Section II, the problem that is considered in this paper is formulated. In Section III, the optimization method of charging/discharging operations considering bus schedule is developed. In Section IV, the model of the retail prices to promote Vehicle-to-Load is presented. In Section V, the portfolio analysis of retail prices to benefit both the retailer and the electric bus operator is conducted. In Section VI, conclusions are presented.

II. Problem formulation

Fig. 1 shows the model of electricity procurement and retail in this paper. The retailer buys the electricity from the electricity market, and the electric bus operator buys the electricity from the retailer according to the retail price. Note that all power flow is used for bus charging and the electric bus operator office demand, and there is no reverse flow to the grid. The electric bus operator optimizes the charging/discharging operations to minimize the electricity cost. However, the timing of the charging/discharging is affected by the electric

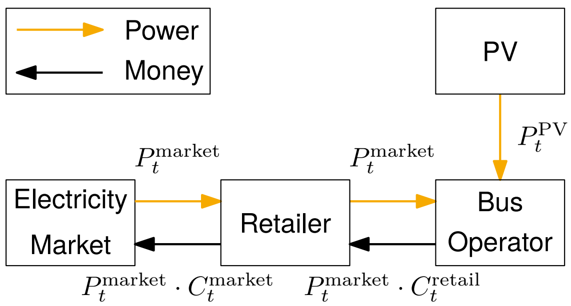


Fig. 1. Model of electricity procurement and retail.

bus schedule which cannot be changed and the electric bus can be charged/discharged at the electric bus operator office. The retailer tries changing the retail price to promote demand response by the electric bus operator. Although the retail price that follows the market price can make the revenue risk of the retailer smaller, the too-dynamic retail price can make the cost risk of the electric bus operator larger. From these discussions, the requirements of the developed approach are

R1) that the charging/discharging operations is optimized with consideration of the electric bus schedule, and
R2) the retail contract is selected to benefit both the retailer and the electric bus operator.

III. Charging/Discharging Operations Optimization Considering Bus Schedule

The optimization problem of the charging/discharging operations of the electric bus is formulated from (1) to (12), where the symbols of the optimization model are listed in TABLE I.

$$\text{minimize} \quad \sum_{t=1}^{t_{\max}} (C_t^{\mathrm{retail}} \cdot P_t \cdot \Delta t) \tag{1}$$

$$\text{subject to } (\forall t \in \mathbb{T})$$

$$D_t + P_t = P_t^{\mathrm{PV}} + P_t^{\mathrm{market}} \tag{2}$$

$$P_t = \sum_i P_{i,t}^c - \sum_i P_{i,t}^d \tag{3}$$

$$X_{i,t}^c,\ X_{i,t}^d \in \{0,1\}\ (\forall i) \tag{4}$$

$$X_{i,t}^c + X_{i,t}^d \leq 1\ (\forall i) \tag{5}$$

$$P_{i,t}^c = P_{i,t}^d = 0\ (\forall i \in \mathbb{B}_t^s \cup \mathbb{B}_t^r) \tag{6}$$

$$0 \leq P_{i,t}^c \leq X_{i,t}^c \cdot P_{\max}^c,\ P_{i,t}^d = 0\ (\forall i \in \mathbb{B}_t^c) \tag{7}$$

$$0 \leq P_{i,t}^d \leq X_{i,t}^d \cdot P_{\max}^d,\ P_{i,t}^c = 0\ (\forall i \in \mathbb{B}_t^d) \tag{8}$$

$$SOC_{i,t+1} = SOC_{i,t}\ (\forall i \in \mathbb{B}_t^s) \tag{9}$$

$$SOC_{i,t+1} = SOC_{i,t} - \frac{\delta}{\eta_r \cdot Q}\ (\forall i \in \mathbb{B}_t^r) \tag{10}$$

$$SOC_{i,t+1} = SOC_{i,t} + \eta_c \frac{P_{i,t}^c \Delta t}{Q}\ (\forall i \in \mathbb{B}_t^c) \tag{11}$$

$$SOC_{i,t+1} = SOC_{i,t} - \frac{1}{\eta_d}\frac{P_{i,t}^d \Delta t}{Q}\ (\forall i \in \mathbb{B}_t^d) \tag{12}$$

TABLE I
Symbols of optimization model.

symbol	description	unit
t	time	–
$t_{\max}$	end time of optimization period	–
$\mathbb{T}$	set of optimization period	–
Δt	time step	hour
D_t	demand of bus operator office at time t	kW
P_t^{PV}	power from PV at time t	kW
P_t^{market}	power from electricity market at time t	kW
P_t	total charging power to battery at time t	kW
P_t^c	charging power to battery at time t	kW
P_t^d	discharging power from battery at time t	kW
$P_{\max}^c$	maximum charging power	kW
$P_{\max}^d$	maximum discharging power	kW
SOC_t	state of charge (SOC) of battery at time t	–
$SOC_{\min}$	minimum SOC of battery	–
$SOC_{\max}$	maximum SOC of battery	–
Q	capacity of battery	kWh
η_c, η_d	charging/discharging efficiency	–
η_r	running efficiency	km/kWh
δ	running distance per round route	km
$\mathbb{B}_t^s$	set of bus in staying	–
$\mathbb{B}_t^r$	set of bus in running	–
$\mathbb{B}_t^c$	set of bus in charging	–
$\mathbb{B}_t^d$	set of bus in discharging	–

The objective function (1) represents minimizing the electricity cost of the electric bus operator. (2) represents the power balance of the electric bus operator office, and note that all power flow is used for bus charging and the electric bus operator office demand, and there is no reverse flow to the grid. (3) represents the total charging power to the battery considering the charging and discharging of multiple buses. (4) and (5) are the binary conditions that represent the state of charging and discharging. (6), (7), and (8) represent the power corresponding to the state of the electric buses. (9), (10), (11), and (12) represent the SOC conditions corresponding to the state of the electric buses.

IV. Model of Retail Prices to Promote Vehicle-to-Load

The retail price that follows the market price can promote demand response of the consumers. In this paper, 5 different retail price models are investigated to that which retail price can benefit both the retailer and the electric bus operator. The models of the market price and the retail price are shown in Fig. 2. Fig. 2(a) shows the conventional fixed price model. It does not change corresponding to the market price and it cannot promote demand response. Fig. 2(b) shows the retail price model with the low price demand response. It achieves demand response by stimulating demand when the market price is low. Fig. 2(c) shows the retail price model with the high price demand response. It achieves demand response by suppressing demand when the market price is high. Fig. 2(d) shows the retail price model with three-step prices. It roughly follows the market price and promotes demand response according to the market price. Fig. 2(e) shows the retail price model according to the real-time market price. It accurately follows the market price and promotes

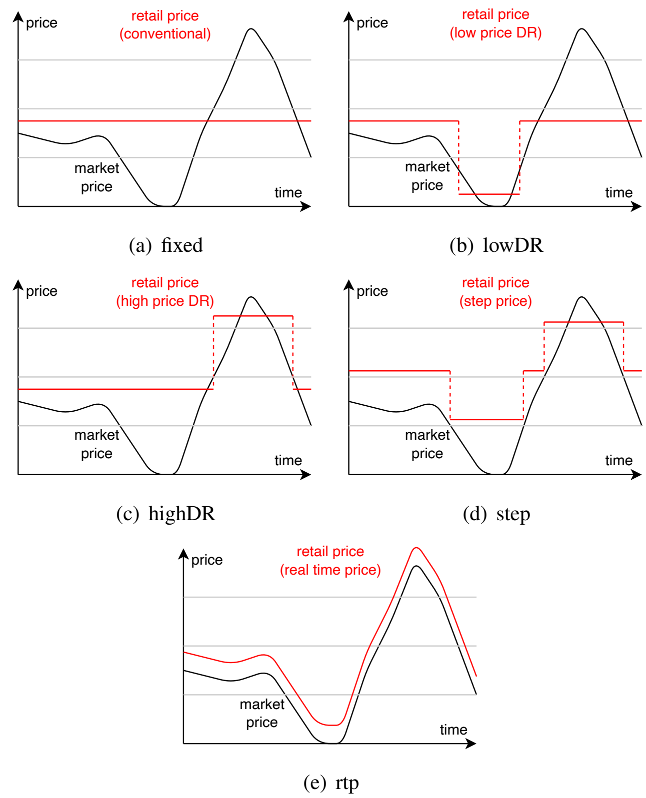


Fig. 2. Model of market price and retail price.

TABLE II
CONDITIONS OF OPTIMIZATION.

condition	description
objective function	minimize electricity cost of bus operator
time step Δt	15 min/1 slot ($\Delta t = 0.25$)
set of optimization period $\mathbb{T}$	96 slot/1 day $t_{\max} = 96$, $\mathbb{T} = \{1, 2, 3, ..., 96\}$
optimized variable	charging/discharging output (P_t^c, P_t^d) and battery SOC (SOC_t)
used data	electricity market price and solar radiation from April 2017 to March 2022

demand response according to the market price. Although the retail price model according to the real-time market price can promote demand response at the most, it can make the risk of the cost of the electric bus operator larger because the electric bus operator cannot follow the price fluctuation completely.

V. PORTFOLIO ANALYSIS OF RETAIL PRICES TO BENEFIT BOTH RETAILER AND BUS OPERATOR

In this section, the optimization problem of the charging/discharging operations of the electric bus with various retail prices is conducted in the model based on the actual bus operator. The portfolio analysis is conducted for the optimization results to investigate the retail price that benefits both the retailer and the electric bus operator.

A. Conditions

In this paper, the numerical case study is conducted on the electric bus route based on the actual bus operator in Hiroshima, Japan, as shown in Fig. 3. Fig. 3(a) shows the electric bus schedule and the magenta areas are the period during which the electric bus is running. The two buses alternatively run the round route as shown in Fig. 3(b). The electricity demand of the electric bus operator office is also defined in Fig. 3(c). The specification of PV at the electric bus operator office is that the power is 30 kW, the azimuth is 0° to south, and the tilt angle is 30°.

For the optimization calculation, the conditions are shown in TABLE II. The data of the electricity market is based on Japan Electric Power eXchange (JEPX) [11]. The price variables are listed in TABLE III and the retail prices in this paper are

TABLE III
PRICE VARIABLES TO PROMOTE DEMAND RESPONSE (DR).

symbol	description	unit
C_t^{market}	market price at time step t	[JPY/kWh]
C_t^{retail}	retail price at time step t	[JPY/kWh]
C^{ave}	average market price in last year	[JPY/kWh]
C^{premiere}	risk premium (= 7 JPY/kWh)	[JPY/kWh]
C^{wheel}	wheeling fee (= 5 JPY/kWh)	[JPY/kWh]

TABLE IV
DETAIL OF RETAIL PRICES.

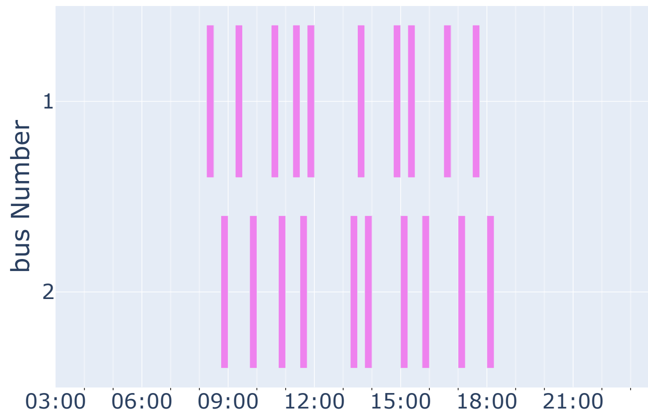
name	description	retail price C_t^{retail} [JPY/kWh]
fixed	conventional	C_t^{retail} in TABLE V
lowDR	low price DR	if $C_t^{\text{market}} \leq 1$ $1 + C^{\text{wheel}}$ else C_t^{retail} in TABLE V
highDR	high price DR	if $C_t^{\text{market}} < 20$ $15 + C^{\text{wheel}}$ else $31 + C^{\text{wheel}}$
step	step price DR	if $C_t^{\text{market}} < 10$ $12 + C^{\text{wheel}}$ else if $10 \leq C_t^{\text{market}} < 20$ $22 + C^{\text{wheel}}$ else if $20 \leq C_t^{\text{market}}$ $32 + C^{\text{wheel}}$
rtp	real-time price DR	$C_t^{\text{market}} + C^{\text{wheel}}$ + retail revenue (5 JPY/kWh)

TABLE V
FIXED RETAIL PRICE [JPY/kWh] BY YEAR.

year	C_t^{retail}	C^{ave}	C^{premiere}	C^{wheel}
2017	20.29	8.29	7.0	5.0
2018	21.8	9.8		
2019	20.88	8.88		
2020	19.17	7.17		
2021	23.05	11.05		
2022	26.03	14.03		

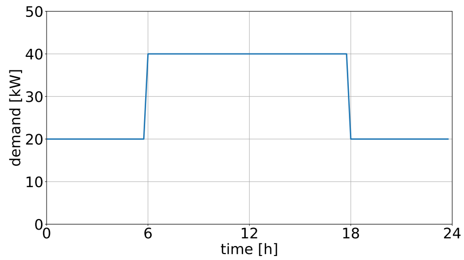
TABLE VI
SPECIFICATION OF ELECTRIC BUS.

specification	value
battery capacity Q	105.6 kWh
battery output $P_{\max}^c$, $P_{\max}^d$	30 kW
charging/discharging efficiency η_c, η_d	0.9
running efficiency η_r	1.56 km/kWh
running distance per round route δ	5 km



(a) Bus schedule. (■) denotes periods in that electric buses are running.

(b) Bus route.



(c) Electricity demand of bus operator office.

Fig. 3. Model of bus operator.

defined in TABLE IV that follows the idea of revenue neutral as far as possible, where the fixed retail price by year is given by TABLE V. The specifications of electric bus is shown in TABLE VI. The optimization calculation is conducted by using Python [12] and Gurobi [13].

B. Optimization result

The optimization of the charging/discharging operations of the electric bus is conducted with various retail prices in Fig. 2.

To focus on the behavior of the charging/discharging operations with demand response, the three days from October 1 to 3 in 2021 are analyzed in step price as an example. Fig. 4 shows the market price and the retail price in step price for these 3 days. In step price, the retail price roughly follows the trend of the market price.

Fig. 5 shows the power management and the SOC trend in the conventional charging operation after the electric bus service. It results in that the electric bus is charged during the market and the retail prices are high and it is not preferable for the cost of the electric bus operator.

Fig. 6 shows the power management and the SOC trend in step price with optimizing the charging/discharging operations. It results that the battery of the electric bus is charged more during the retail price is low and is discharged during the retail price is high. Note that all power flow after the optimization is used for bus charging and the electric bus operator office demand, and there is no reverse flow to the grid.

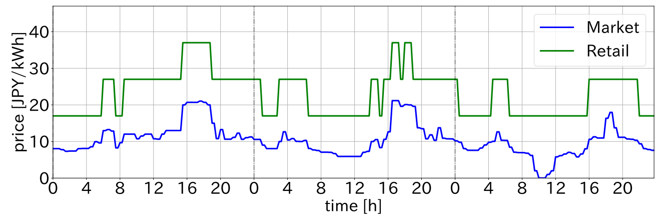
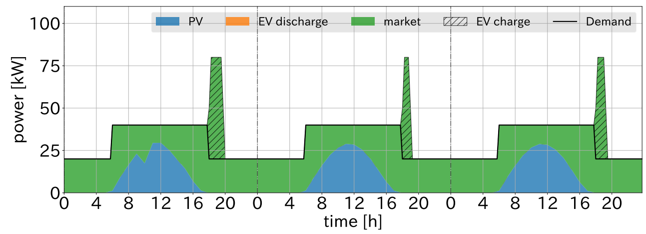
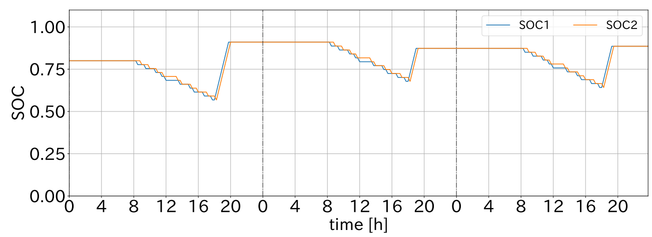


Fig. 4. Market price and retail price in step price.

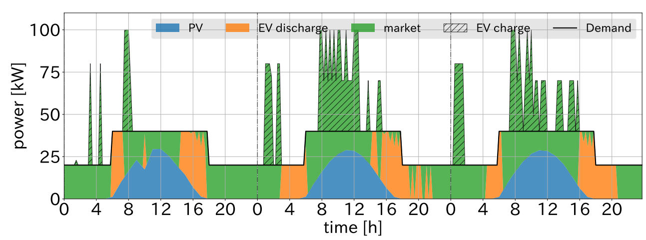


(a) Power management.

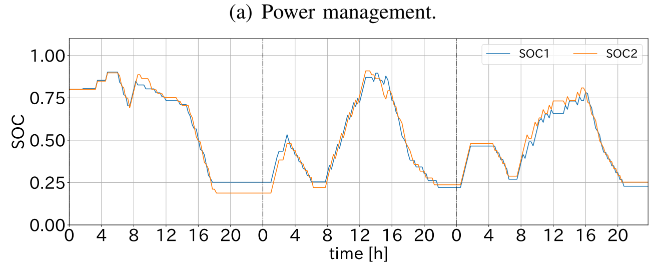


(b) SOC trend.

Fig. 5. Conventional charging operation after bus service.



(a) Power management.

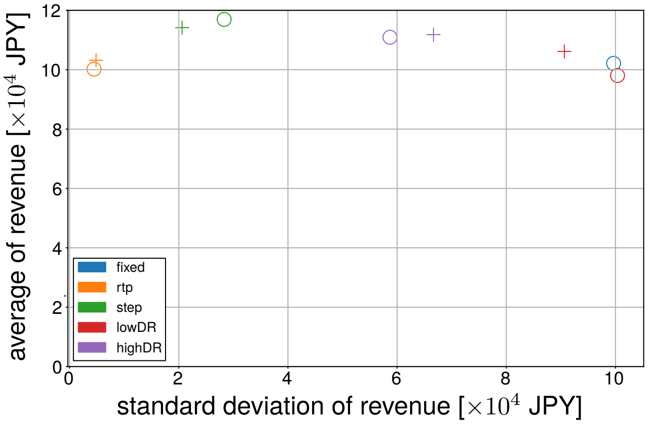


(b) SOC trend.

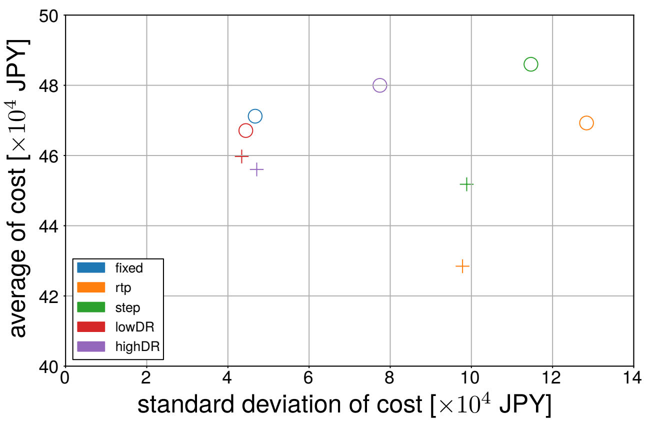
Fig. 6. Optimized charging operation in step price.

C. Portfolio analysis in various retail contracts

The key point that is identified in this paper is the retail price that can benefit both the retailer and the electric bus operator. The benefit of the retailer and the electric bus operator can be analyzed by the portfolio that consists of the average and standard deviation of the revenue of the retailer and the cost



(a) Revenue portfolio of retailer.



(b) Cost portfolio of electric bus operator.

Fig. 7. Portfolio analysis in various retail contracts. (◯) denotes conventional charging operation after bus service, and (+) denotes optimized charging operation.

of the electric bus operator. The monthly portfolio analysis in various retail contracts is shown in Fig. 7.

Fig. 7(a) shows the revenue portfolio of the retailer. It shows that the standard deviation of the revenue of the retailer becomes small when the retail price follows to the market price. In contrast, the average value of revenue does not change much corresponding to the retail price. It results in the retail price that follows the market price benefits the retailer to make the business risk smaller.

Fig. 7(b) shows the cost portfolio of the electric bus operator. It shows that the average cost of the electric bus operator is reduced by the optimization of the charging/discharging operations. The standard deviation of the cost of the electric bus operator can be reduced by lowDR, fixed, and highDR retail prices. Although the real-time price can make the standard deviation of the revenue of the retailer smaller, it makes the standard deviation of the cost of the electric bus operator much larger, and it cannot be accepted by the business risk of the electric bus operator. As a result, the lowDR retail contract is the best because it benefits both the retailer and the electric bus operator.

VI. Conclusion

This paper identifies a suitable contract that benefits both the retailer and the electric bus operator to promote Vehicle-to-Load as demand response. The electric bus operator optimizes charging/discharging operations in various retail contracts, and the characteristics of the revenue for the retailer and the cost of the electric bus operator are analyzed in each case. By optimizing the charging/discharging operations of the electric bus with various retail prices in mixed-integer programming, it is possible to benefit both the retailer and the electric bus operator. The results show that two-step price for stimulating demand is found to be the best in terms of appropriate risk allocation between the retailer and the electric bus operator. Cooperation between retailers and electric bus operators will be important for the practical realization of demand response with electric vehicles in the future. Ongoing researches focus on the consideration of the battery degradation because of charging/discharging, the faster optimization calculation method in mixed integer programming, and the experiment and the social implementation with actual bus companies.

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