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# A smart hybrid pole with street lighting and EV charging based on DC micro-grid and renewable energy

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**Abstract.** In order to efficiently utilize renewable energy and solve roadside fast charging of Electric Vehicle (EV) problem, a smart hybrid pole system is proposed in this paper, which integrated with renewable energy Street Lighting Pole (SLP) and EV charging. Besides, smart hybrid pole can also serve as the backup power for traffic lights. In this system, several renewable energy SLPs are coupled together by Direct Current (DC) micro-grid with storage battery, so it is suitable for both DC fast charging and slow charging for EV. More importantly, the energy efficiency in this system can become much higher than alternating current (AC) EV charging system, because renewable energy power such as photovoltaic (PV), load and energy storage are all DC subsystem. Then for studying the suitable number in a group of smart hybrid pole, the group model of smart hybrid pole is presented. In addition, the hybrid pole energy storage system can be controlled by a cloud management platform, so it is convenient to make the decision to charge or discharge according to the different power prices. The smart hybrid pole solution is conducive to EV charging and the efficient application of renewable.

**Keywords:** smart pole; street lighting; EV charge; micro-grid; renewable energy; energy storage; cloud management.

## 1. Introduction

Nowadays, energy crisis and environment pollution have become the global problem, and the increasing use of energy caused climate change. However, the renewable energy, clean energy, other distributed generation (DG) such as solar-based photovoltaic (PV) and wind generation, some changes of energy consumption such as the use of light-emitting diode (LED) lighting [1-3] and new transport EV [4-6], positively contribute to the reduction of the carbon footprint of electricity generation.

The new-energy vehicles, especially EV, has been quickly developed in recent years [4,5]. In fact, automakers, including Germany-based BMW and Audi, Japan-based Toyota and Nissan, the US-based General Motors and Tesla, and China-based BYD and Roewe, launched a series of new-energy vehicle models, which marks the initial popularity of new-energy vehicles. As expected, China has a rapidly growing market of new-energy vehicles. In 2016, 517,000 new-energy vehicles were produced and 507,000 new-energy vehicles were sold in China, with the growth of 52% and 53% respectively compared to the last year.

However, EV charging points and service do not match the growing trend of EV in China. EV charging points increased with the growth of 12% compared to 2015. Until June 2016, China's total public charging poles are 81,000 and the private charging piles are 55,000. The ratio of car to pole is about 8:1, so it is far below the theoretical ratio of 1:1~1.2. Currently, it needs to build more charging poles [6]. In 2020, 435 thousand charging points will be built in Beijing to satisfy the requirement for 600 thousand EV.

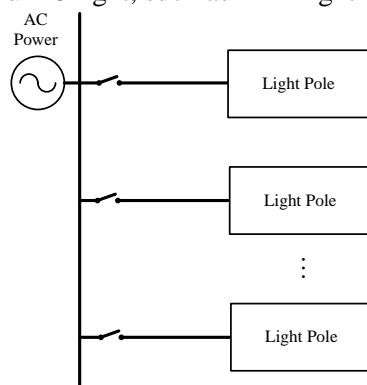
The construction of charging points needs to lay plenty of cable in every corner of the city, which means large cost. To reduce expenses, street-lighting pole with EV charging system is presented. The



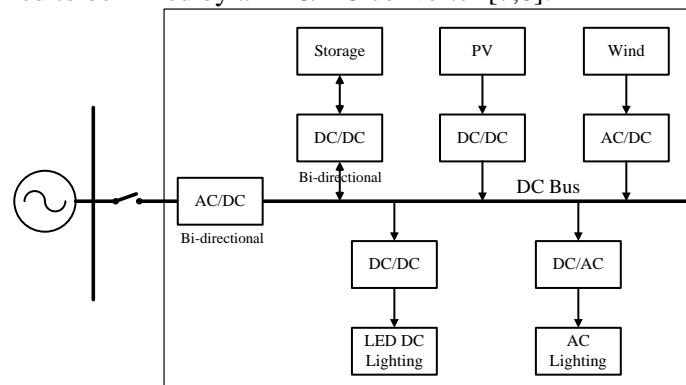
distribution characteristic of street-lighting is similar with the distribution characteristic of EV charging, so charging points can be constructed based on the system of street-lighting. However, it is only suitable for EV slow charging because the capacity of cable for street lighting pole is not enough for EV fast charging. In this paper, a smart hybrid pole with street-lighting and EV-charging systems, which can be used to both fast charging and slow charging for EV, is proposed based on DC micro-grid, renewable energy and energy storage.

## 2. Architecture of lighting system

It is well known that the architecture of traditional street lighting system is presented in Figure 1. In this system, traditional alternating current (AC) street light can be supported by AC power directly, and DC light, such as LED light is required to be linked by an AC/DC converter [7,8].



**Figure 1.** The traditional street lighting system



**Figure 2.** The architecture of renewable energy street lighting pole

When the renewable energy DG, such as PV and wind generation, are introduced into street lighting system, DC bus and storage devices such as battery are necessary in order to reduce the times of energy conversion to get a highly efficient system. Meanwhile, the energy storage can ensure the voltage stability and operate in island mode in long time. The architecture of renewable energy street lighting pole is presented in Figure 2. In this system, both AC and DC light can be considered.

## 3. Architecture of smart hybrid pole

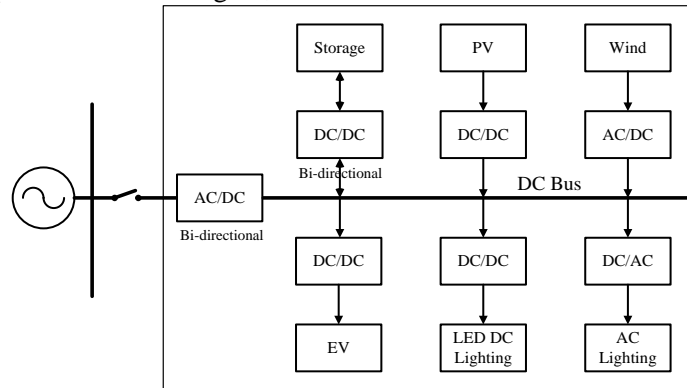
In recent years the hybrid poles with street lighting and EV changing have been developed by different companies respectively. In fact, this kind of hybrid pole is only suitable for slow charging for EV.

In order to fast charging for EV, a smart hybrid pole with street-lighting is proposed in this section. EV charging system is added to the renewable energy street lighting pole as shown in Figure 3, then the hybrid poles are integrated by use of a DC micro-grid [9] as shown in Figure 4. In this micro-grid system, smart hybrid poles are connected by DC bus. In this case, the part of EV charging can get power from AC grid, DC micro-grid and storage unit directly, so theoretically it is suitable for EV fast charging if the power controlled reasonable.

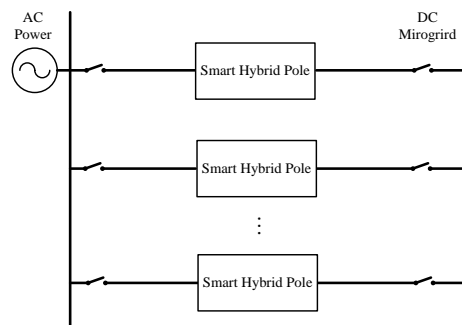
Compared to island hybrid pole, besides it can provide fast charging service, the integrated smart hybrid poles provide following benefits:

- The micro-grid system is fairly flexible. The smart hybrid poles can operate in grid-connected mode or island mode;
- The system has more safety and reliability. With the connection of DC micro-grid, the power can be dispatched between hybrid poles, so the DC bus voltage is in stable condition;
- It has more economical efficiency for consumer. Every smart hybrid pole with storage can be management by DC micro-grid, so it can reduce its operational expenses in accordance with peak-valley price;
- The system can provide UPS services for emergency.

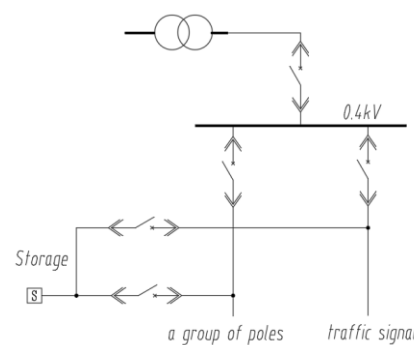
Additionally, smart hybrid pole can also serve as the backup power for traffic lights, as shown in Figure 5. When the power grid malfunctions, the storage battery in smart hybrid pole can provide emergency electric power for traffic signal, which avoids traffic disturbance.



**Figure 3.** The smart hybrid pole with street lighting and EV charging



**Figure 4.** The integrated hybrid poles by a DC micro-grid



**Figure 5.** The backup power for traffic signal

#### 4. The group model of smart hybrid pole

For studying the suitable number in a group of smart hybrid pole, the group model of smart hybrid pole is proposed in this section.

The power of street lighting is usually only 0.2 kW, and the power of slow charging for EV is 7 kW ( $220\text{ V} \times 32\text{ A}$ ). Therefore, the power of the EV charging poles should be primary part of the capacity of the distribution box of municipal road.

Supposing that the rated slow charging power is  $a$  kW, and the rated fast charging power is  $n \times a$  kW, which is  $n$  times more than the rated slow charging power ( $n \in \mathbb{Q}^+$ ,  $n > 1$ ); the number of poles is  $t$  ( $t \in \mathbb{Q}^+$ ,  $t \geq n$ ). Traditional poles with street light and EV charging only support slow charging. Taking  $t = 4$  as an example, there should be 5 cases as shown in Table 1. The possibility of each case is hard to be calculated due to different time and position. For simplifying, supposing that the probability of each situation is equal, the average power per case is  $2a$  kW, and the average power per pole is  $0.5a$  kW.

**Table 1.** Average power in the case of 4 poles with only slow charging

Case	Pole 1	Pole 2	Pole 3	Pole 4	Total power (kW)
1	0	0	0	0	0
2	$a$	0	0	0	$a$
3	$a$	$a$	0	0	$2a$
4	$a$	$a$	$a$	0	$3a$

5	$a$	$a$	$a$	$a$	$4a$
	Average power per case				$2a$
	Average power per pole				$0.5a$

Table 1 is changed to the following  $5 \times 4$  matrix:

$$A_{5 \times 4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ a & 0 & 0 & 0 \\ a & a & 0 & 0 \\ a & a & a & 0 \\ a & a & a & a \end{bmatrix} \quad (1)$$

The equal probability of each situation  $f_t$  in matrix form under  $t = 4$  is:

$$f_4 = [0.2 \quad 0.2 \quad 0.2 \quad 0.2 \quad 0.2] \quad (2)$$

Supposing that the matrix  $M_t$  under  $t = 4$  is for the accumulation of cases:

$$M_4 = [1 \quad 1 \quad 1 \quad 1 \quad 1]^T \quad (3)$$

The average power per pole  $P_{avg,t}$  under  $t = 4$  is:

$$P_{avg,4} = 0.25 \times f_4 \times A_{5 \times 4} \times M_4 = 0.5a \quad (4)$$

Extending to each  $t$ , there should be  $(t+1)$  cases as shown in the following  $(t+1) \times t$  matrix; with the same probability of each situation, the average power per case is  $0.5ta$  kW, and the average power per pole is also  $0.5a$  kW.

$$A_{(t+1) \times t} = \begin{bmatrix} 0 & \cdots & \cdots & 0 & 0 \\ a & 0 & \cdots & 0 & 0 \\ a & a & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ddots & 0 & 0 \\ a & a & \cdots & a & 0 \\ a & a & \cdots & a & a \end{bmatrix} \quad (5)$$

$$f_t = [(t+1)^{-1} \quad \cdots \quad (t+1)^{-1}] \quad (6)$$

$$M_t = [1 \quad \cdots \quad 1]^T \quad (7)$$

$$P_{avg,t} = t^{-1} \times f_t \times A_{(t+1) \times t} \times M_t = 0.5a \quad (8)$$

If the poles can provide the serves of slow and fast charging,  $t$  smart hybrid poles will maximally at the same time support  $\lfloor t/n \rfloor$  poles with fast charging with total  $t*a$  kW power limit, ( $\lfloor t/n \rfloor$  means that  $t/n$  is rounded down). In the case of  $t = 4$  and  $n = 4$  as shown in Table 2, the average power per case is  $2.6a$  kW, and the average power per hybrid pole is  $0.65a$  kW. So, the expectation value of each hybrid pole power with slow and fast charging is more than with only slow charging, which means efficiency promotion.

**Table 2.** Average power in the case of 4 hybrid poles with slow and fast charging

Case	Pole 1	Pole 2	Pole 3	Pole 4	Total power (kW)
1	0	0	0	0	0
2	$a$	0	0	0	$a$
3	$a$	$a$	0	0	$2a$
4	$a$	$a$	$a$	0	$3a$
5	$a$	$a$	$a$	$a$	$4a$
	Average power per case				$2.6a$
	Average power per hybrid pole				$0.65a$

Table 2 is changed to a  $5 \times 4$  matrix as following:

$$B_{5 \times 4} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 4a & 0 & 0 & 0 \\ a & a & 0 & 0 \\ a & a & a & 0 \\ a & a & a & a \end{bmatrix} = A_{5 \times 4} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ 3a & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (9)$$

The average power per pole  $P'_{avg,t}$  under  $t = 4$  is:

$$P'_{avg,4} = 0.25 \times f_4 \times B_{5 \times 4} \times M_4 = 0.65a \quad (10)$$

Extending to each  $t$  and  $n$ , the cases is shown in the following  $(t+1) \times t$  matrix:

$$B_{(t+1) \times t} = \begin{bmatrix} 0 & \dots & \dots & 0 & 0 \\ na & 0 & \dots & 0 & 0 \\ na & na & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ddots & 0 & 0 \\ a & a & \dots & a & 0 \\ a & a & \dots & a & a \end{bmatrix} = A_{(t+1) \times t} + \begin{bmatrix} 0 & \dots & \dots & 0 & 0 \\ (n-1)a & 0 & \dots & 0 & 0 \\ (n-1)a & (n-1)a & \ddots & \vdots & \vdots \\ \vdots & \vdots & \ddots & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 \\ 0 & 0 & \dots & 0 & 0 \end{bmatrix} \quad (11)$$

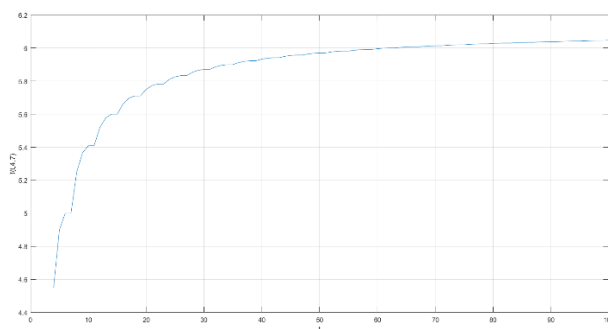
The average power per pole  $P'_{avg,t}$  is:

$$P'_{avg,t} = t^{-1} \times f_t \times B_{(t+1) \times t} \times M_t \quad (12)$$

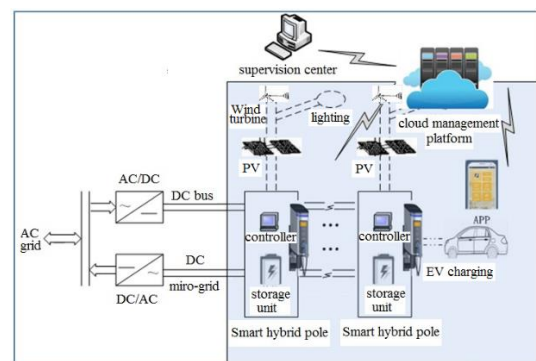
Supposing that the Average power per pole is  $f(t, n, a)$ , which can be calculated as formula:

$$f(t, n, a) = P'_{avg,t} = [0.5 + \frac{2 \left\lfloor \frac{t}{n} \right\rfloor (t+1) - \left\lfloor \frac{t}{n} \right\rfloor \left( \left\lfloor \frac{t}{n} \right\rfloor + 1 \right) n}{2(t+1)t} \cdot (n-1)]a \quad (13)$$

In the actual project, hybrid poles have rated slow and fast charging power with stationary, so  $n$  is constant. Take 7 kW slow charging and 28 kW fast charging as an example ( $n = 4$ ,  $a = 7$ ),  $f(t, 4, 7)$  is shown in Figure 6 by MATLAB.  $f(t, 4, 7)$  increases rapidly when  $t$  is from 4 to 20, and it rises slowly when  $t$  is more than 20. Therefore, a set of 20 smart hybrid poles is more efficient in ideal conditions. In actual situation, the optimum number of smart hybrid poles also depend on the cost of electric system and actual road light planning and design.



**Figure 6.** The functional image of average power per hybrid pole with power limit



**Figure 7.** The management system of smart hybrid poles

## 5. Management of Smart hybrid pole

In order to control system operation and maintain stability, a powerful management system is extremely essential. A management system is proposed for DC micro-grid integrated hybrid poles. In the management system, as shown in Figure 7, the charging terminal control and metering system, and the client application are combined to cloud intelligence management platform to collect big data, integrate scheduling, optimize storage, remote monitoring and other functions. Besides, management system can control the charge and discharge of storage unit judging by time-of-use electricity price. This management system has economic benefit.

## 6. Conclusions

In this paper, a smart hybrid pole with street lighting and EV charging was proposed, and the integrated hybrid poles with management system were studied. The conclusions and suggestion are summarized as following:

- A structure of smart hybrid pole system was proposed. The proposed hybrid pole can operate in grid-connected mode or island mode, and the stability of DC bus voltage can be supported by the storage.
- The smart hybrid poles system integrated by DC micro-grid is more safe and reliable. With the cloud management platform, the power can be dispatched between AC grid and DC micro-grid or between hybrid poles.
- With the use of cloud management platform, it is easy to make the decision on the basis of the peak-valley price to charge or discharge, so it has more economical efficiency for consumer.

In addition, the next step we will focus on further research on specific calculations and experiments and analyse the parameters and energy efficiency of different poles.

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