

# Design of Intelligent Power Supply System for Expressway Tunnel

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**Abstract:** Tunnel lighting program is one of the key points of tunnel infrastructure construction. As tunnels tend to handle remote locations, power supply line construction generally has been having the distance, investment, high cost characteristics. To solve this problem, we propose a green, environmentally friendly, energy-efficient lighting system. This program uses the piston-wind which cars within tunnel produce as the power and combines with solar energy, physical lighting to achieve it, which solves the problem of difficult and high cost of highway tunnel section, and provides new ideas for the future construction of tunnel power supply.

## 1. Introduction

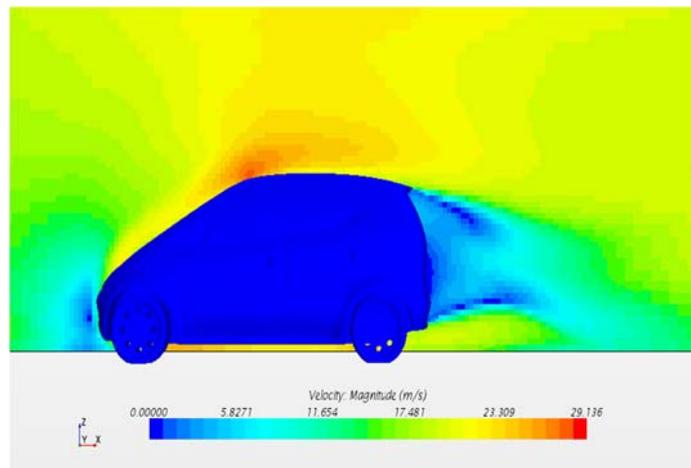
The work is based on the passive wind within the tunnel as the source, the use of wind power principle design of the tunnel light dedicated wind turbine to collect wind energy, so as to store in the form of electricity to meet the highway tunnel power supply needs, while the study outside the tunnel Photovoltaic and tunnel light fan and other green clean energy complementary use and integrated storage technology, combined with LED lighting and signal control technology to find the best tunnel green energy lighting and power supply system solutions, analysis and design of new wind, light, storage integration Dedicated lighting system to solve the problem of local power supply to the tunnel. At the same time, the paper studies the complementary use of green clean energy and integrated storage technology and combines the LED lighting and signal control technology to find the optimal green energy lighting and power supply system. It analyzes and designs new wind, light, storage and integration of special lighting system to solve the problem of local power supply to the tunnel.

## 2. Design of the program

### 2.1. The collection of wind-energy

*2.1.1. Analysis of vehicle passive wind characteristics and feasibility of energy collection.* By querying the relevant information, we found that the wind speed in the high-speed tunnel, due to space constraints, will be greater than the car in the open external environment of the passive wind speed. Based on this, it is of reference value to use STAR-CCM+ to simulate the vehicle aerodynamics under open conditions. We assume that the vehicle speed remains 100km/h and use CFD processing, getting the results shown in the following figure 1.





**Figure 1.** Result of numerical simulation

According to the simulation results, we know that the available wind-speed is about 11-17 m/s, which is able to achieve the requirements of fan rotation. By studies, in addition to the piston wind, the lateral wind also can be used, which is easier to be collected and is faster than the piston wind.

*2.1.2. Location and design of the fan.* According to the tunnel structure, lighting facilities and ventilation devices will be installed above the tunnel and both sides have rich space, which provide a favorable position for the installation of the fan. Apart from that, in the introduction and analysis of reference [2], the result is that the installation of the fan on both sides of the tunnel will not only increase the wind resistance, but will be more conducive to the vehicle driving, reducing the loss caused by wind resistance. Smaller, wind power generation efficiency is higher, easy to get lower wind speed.

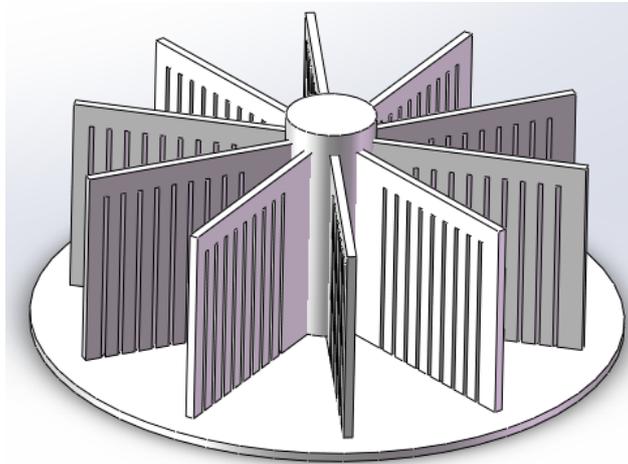
Table.1 shows the different fans and their advantages and disadvantages. Combined with the above-mentioned tunnel space structure, we can find that vertical wind generators are suitable as wind collection devices and take the horizontal installation.

**Table.1** The Types of Fan

Type	Advantages	Disadvantages	Legend
Three - blade wind turbine	Mature technology	The impact of the wind is relatively large	
H-type vertical wind turbine	Smaller size, higher wind power efficiency	Center bar easy to fold, the number of leaves limit the maximum wind speed	
S-type vertical wind turbine	Smaller, wind power generation efficiency is higher, easy to get lower wind speed	Center bar easy to fold	

According to the experiment, the existing fan structure is only used for large fans, which is not able to this condition. Refer to the aerodynamic characteristics of feathers falling, we can be inspired. As a consequence, we design the new fan structure as shown in Fig.2. And we carried out actual testing of blade structure. We use two different kinds of fans for the experiment; as a result, it is clear that new

blades are easier to start at low wind speeds and faster at the same speed. This shows that the structure is more suitable for tunnel wind energy collection.

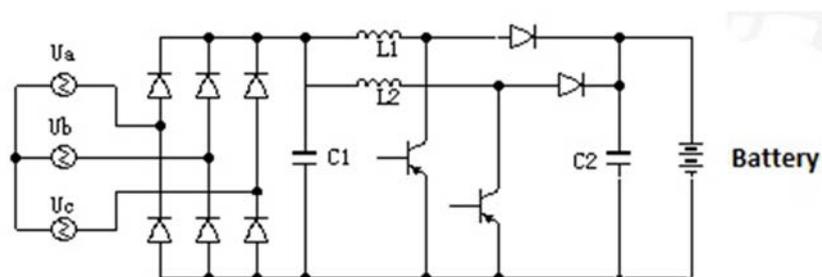


**Figure 2.** New structure of fan

## 2.2. Energy storage device

There is much mature technology, which can be applied in terms of energy storage. After comparing the various options, we decided to take the following plan. In view of the technology for the existing mature technology, we only do a brief description.

**2.2.1 The main circuit of the charger.** Wind turbines usually use three-phase permanent magnet generators, and its output voltage amplitude and frequency instability, which changes with the wind speed in the tunnel. So we use a kind of coupled induct-coupled parallel Boost technique. The Boost circuit can broaden the speed range of the wind turbine, and reduce the withstand voltage requirements of the power device and the input current ripple, so as to improve the working efficiency. In the meantime, the Boost technology can solve the parallel operation of the design process Flow problem. The schematic of the BOOST circuit is shown below:

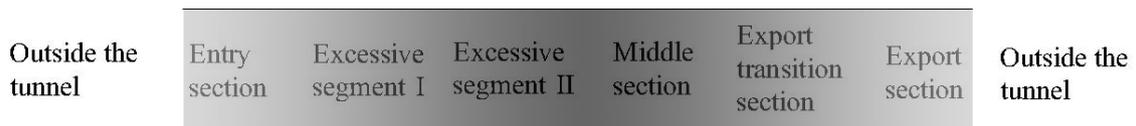


**Figure 3.** Tunnel lighting section division

**2.2.2. Three-stage charging process.** Three-stage battery charge is divided into constant current, constant pressure, floating charging. During the constant current charging stage, the negative feedback of the current plays a leading role in controlling the charge current constant. In the constant-voltage charging stage, the negative feedback of the voltage plays a leading part in controlling the charge voltage within a given range. In floating charge phase, the voltage negative feedback play a leading role, the charge voltage is also controlled within a given range, but this time the voltage is less than the constant voltage charging stage voltage. Through the sub-charging, we can effectively extend the battery life, and reduce the occurrence of accidents.

2.3. Lighting control

2.3.1. Segment analysis. Due to the special structure of the tunnel, there are many "hidden holes effect" and "black hole effect" which could bring security risks. Tunnel lighting is generally divided into the entrance section, the transition section, the middle section and the export section, which is shown in Figure 4.



**Figure4.** Tunnel lighting section division

(1) Entry section

In order to reduce the "black hole effect" when people are entering the tunnel, the brightness of the entrance section should be set by the calculation of the formula (1),

$$L_{th} = k * L_{20}(S) \tag{1}$$

Where:

$L_{th}$  : The brightness of the entry section

$k$  : The entrance section brightness reduction factor, according to the table 2.

$L_{20}(S)$  : The brightness outside of the hole

**Table.2** The value of k

Traffic volume $N$ ( Car /h)		k			
One-way two-lane traffic	Two-way two-lane traffic	the speed $v_i$ (km/ h) 100	the speed $v_i$ (km/ h) 80	the speed $v_i$ (km/ h) 60	the speed $v_i$ (km/ h) 40
$\geq 2400$	$\geq 1300$	0.045	0.035	0.022	0.012
$\leq 700$	$\leq 360$	0.035	0.025	0.015	0.01

The length of the entrance section is calculated as follows

$$D_{th} = 1.154D_s - \frac{h-1.5}{\tan 10^\circ} \tag{2}$$

Where:

$D_{th}$  : The length of the entrance section

$D_s$  : Lighting parking line of sight, according to the table 3

$h$  : Clearance within the hole height

**Table.3** Lighting stop sight

$v_i$ (km/ h)	Longitudinal slope(%)									
	-4	-3	-2	-1	0	1	2	3	4	
100	179	173	168	163	158	154	149	145	142	
80	112	110	106	103	100	98	95	93	90	
60	62	60	58	57	56	55	54	53	52	
40	29	28	27	27	26	26	25	25	25	

(2) Transition section

Transition section is composed of three parts,  $TR_1$ ,  $TR_2$ ,  $TR_3$ . The brightness of the lighting section is shown in Table 4.

**Table.4** Transition section brightness

Lighting section	$TR_1$	$TR_2$	$TR_3$
brightness	$L_{lr1}=0.3L_{th}$	$L_{lr2} = 0.1L_{th}$	$L_{lr3} = 0.035L_{th}$

The lengths of each section of the transition section are taken as Table 5.

**Table.5** Transition length

Driving speed $v_i$ (km/ h)	$D_{tr1}$ (m)	$D_{tr2}$ (m)	$D_{tr3}$ (m)
100	106	111	167
80	72	89	133
60	44	67	100
40	26	44	67

(3) Middle section

The brightness of the middle section is in Table 6.

**Table.6** Middle section brightness

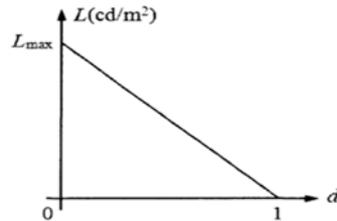
Driving speed $v_i$ (km/ h)	$L_{in}$ (cd/ $m^2$ )	
	One-way two-lane traffic $N > 2400car / h$	One-way two-lane traffic $N < 700car / h$
	Two-way two-lane traffic $N > 1300car / h$	Two-way two-lane traffic $N < 360car / h$
100	9.0	4
80	4.5	2
60	2.5	1.5
40	1.5	1.5

(4) Export section

In the one-way traffic tunnel, the length of the export section should be taken 60 m and the brightness should be taken as the middle section of the brightness of 5 times. In the two-way traffic tunnel, there is no exit section of the lighting.

2.3.2. *LED step-less dimming mode: pulse width shunt dimming.* Compared with other methods, PWM shunt dimming with the characteristics of high security, high precision and fast dynamic response is more suitable for tunnel LED lighting.

Using the duty cycle to control the brightness output, the tunnel section's maximum brightness is  $L_{\max}$ , with PWM=0. And  $0\text{cd}/\text{m}^2$  is corresponding with PWM=1. The resulting relationship between duty cycle and brightness is shown in the figure 5.



**Figure.5** Duty cycle and the relationship between brightness

The function of the duty cycle is expressed as follows

$$d = 1 - \frac{L}{L_{\max}} \quad (3)$$

Daytime dimming function is shown in the formula (4)~(10).

$$d_{th} = 1 - 0.00476 \times \left[ \left( k_d + \left( \frac{N - N_d}{N_u - N_d} \right)^2 \times (k_u - k_d) \right) \times L_{20}(S) + \left( \frac{V - V_d}{V_u - V_d} \right)^2 \times (L_u - L_d) \right] \quad (4)$$

$$d_{th} = 1 - 0.00448 \times \left[ \left( k_d + \left( \frac{N - N_d}{N_u - N_d} \right)^2 \times (k_u - k_d) \right) \times L_{20}(S) + \left( \frac{V - V_d}{V_u - V_d} \right)^2 \times (L_u - L_d) \right] \quad (5)$$

$$d_{th} = 1 - 0.00470 \times \left[ \left( k_d + \left( \frac{N - N_d}{N_u - N_d} \right)^2 \times (k_u - k_d) \right) \times L_{20}(S) + \left( \frac{V - V_d}{V_u - V_d} \right)^2 \times (L_u - L_d) \right] \quad (6)$$

$$d_{in} = 1 - 0.08065 \times \left[ L_d + \left( \frac{V - V_d}{V_u - V_d} \right) \times (L_u - L_d) \right] \quad (7)$$

$$d_E = 1 - 0.0893 \times \left[ L_d + \left( \frac{V - V_d}{V_u - V_d} \right) \times (L_u - L_d) \right] \quad (8)$$

$$d_{Eir} = 1 - 0.1205 \times \left[ L_d + \left( \frac{V - V_d}{V_u - V_d} \right) \times (L_u - L_d) \right] \quad (9)$$

$$d_{EM} = 1 - 0.16129L_{EM} \quad (10)$$

Similarly, you can get the night dimming functions.

In the tunnel lighting dimming optimization algorithm which is described above, the three parameters which are  $L_{20}(S)$ ,  $V$ ,  $N$ , are transmitted to the control center by field acquisition, and the other parameters are determined according to the algorithm.

**2.3.3. Speed and traffic flow detection device.** The system uses a high and a low in two pairs of infrared detector detection. Two infrared radiation signal are parallel accessed to signal line. As long as any one of the signal triggers, the system will respond to the road signal. This type of detection technology has been quite mature, so it does not elaborate.

**2.3.4. Illumination collection device.** Select the illumination sensor  $CY-30$  as the illumination information acquisition module. When the illumination information is collected, controller needs to collect the data to the brightness, and the data would be sent to the wireless control system for intelligent control.

**2.3.5. Design of wireless control system for highway tunnel lighting.** The entire tunnel lighting wireless control system as shown in the figure7, is composed by the monitoring computer, the local controller  $PLC S7-200$ ,  $ZigBee$  network, monitoring computer wireless data transceiver node, wireless sensor nodes and wireless control  $LED$  lighting nodes. Infinite sensor module is to collect vehicle speed, traffic information and the brightness information inside/outside of the hole. After the signal conditioning by the wireless module to send out, the communication node  $ZigBee$  network transmission  $CC2430$  would sent it to the monitoring computer. The monitoring computer receives the data information, carries on the fuzzy control algorithm operation and outputs the illumination control command data, passing by the  $ZigBee$  wireless transmission way to the  $CC2430$  module of the wireless control  $LED$  first. After the analysis, the  $LED$  could be dimmed or switching controlled.

### 3. Conclusion

In this paper, for the energy sources, using passive wind as a source of energy could reduce the energy loss, which is environmental friendly. Additionally, according to the Chongqing Traffic Research and Design Institute of research shows that: LED step-less control comparing to the use of hierarchical control of similar lamps can be 40% energy saving. To achieve the purpose of energy-saving emission reduction and it will achieve good results, which shows that our research and proposals is very efficient for the use of energy and the cost savings is very impressive.

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