Study on Application of Solar Energy in Highway

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Abstract. In recent years, the construction of large-scale electromechanical facilities and smart roads in the highway network has not only improved the level of operation safety but also generated a huge demand for electric energy, the highway transportation industry has become one of the key energy consumption industries second only to industry and construction. Solar energy has become a kind of green energy that has attracted more and more attention among various new energy sources due to its energy-saving, clean, zero-emission, wide-ranging and safe characteristics. This paper analyzes the distribution of solar photovoltaic resources in China's highway network; puts forward the solar energy three-dimensional clean energy supply network technology which is suitable for highway scene, fully relying on and optimize the use of road network linear areas such as road surface space, three-dimensional space along the road to develop solar photovoltaic isolation barriers, etc. can be developed along the line, so as to build a three-dimensional road solar clean energy network that combines "points, lines and sections", so that green and clean energy can be provided to a large number of electricity facilities and equipment along the highway, as well as to surrounding cities and villages, making the highway become the transport network carrying the flow of people and logistics, vehicle-road cooperative intelligent information network and clean energy supply network.

1 Background

The report to the 19th CPC National Congress calls for unswervingly implementing the vision of innovative, coordinated, green, open and shared development. The development and utilization of clean energy has become the only way to alleviate the increasingly tight resource constraints and the increasingly serious environmental pollution in China¹, which is the basic strategy for China's economic and social development during the 13th Five-Year Plan period and for a long time to come. Statistics of 2016 Transportation Industry Development Statistical Bulletin show that: by the end of 2016, China had a total mileage of 4,696,300 kilometers of roads open to traffic, of which 130,970 kilometers of highways were open to traffic, ranking first in the world. In addition to carrying people and logistics to complete transportation, the rich space resources, pavement resources, along the service area, toll station, management center and roadside slope and other resources of highway can also be utilized. The use of solar clean energy is also one of the important technical approaches to the implementation of national ecological civilization construction, green traffic and green road construction in the road transportation industry. Solar highway is an important measure for the transportation industry to implement the national ecological civilization strategy and the concept of green development in the new era, and is also the practice of

green traffic and green road construction requirements, which has important economic value and social benefits.

2 Distribution of solar photovoltaic resources in China

China is one of the countries with abundant solar energy resources. Over 2/3 of the total area of the country, the annual sunshine duration is more than 2,000 hours, and the annual solar radiation is more than 5000MJ /m². According to statistical analysis, the total solar radiation received by China's land area per year is $3.3 \times 103 \sim 8.4 \times 103$ MJ/m², which is equivalent to the reserves of 2.4 x 10.4 billion tons of standard coal.

According to the classification standard of the China Meteorological Administration Wind and Solar Energy Assessment Center, China's solar energy resource areas are divided into the following four categories (Figure 1).



Fig 1 Expressway and regional distribution of solar energy resources

2.1 Class I solar photovoltaic resource areas (with rich resources)

Annual solar radiation \geq 6800MJ/m² (approximately \geq 5.1kwh/m²). Equivalent to the combustion heat of 230kg standard coal. It mainly covers the Qinghai-Tibet Plateau, northern Gansu, northern Ningxia, southern Xinjiang, northwestern Hebei, northern Shanxi, southern Inner Mongolia, southern Ningxia, central Gansu, eastern Qinghai, and southeastern Tibet.

2.2 Class II solar photovoltaic resource areas (with relatively rich resources)

The annual solar radiation is 5850~6680MJ/m² (approximately 4.5~5.1kwh/m²), equivalent to the combustion heat of 180~230kg standard coal. It mainly covers Shandong, Henan, southeastern Hebei, southwestern Shanxi, northern Xinjiang, Jilin, Liaoning, Yunnan, northern Shaanxi, southeastern Gansu, southern Guangdong, southern Fujian, northern central Jiangsu and northern Anhui.

2.3 Class III solar photovoltaic resource areas (with ordinary resources)

The annual solar radiation is 5000~5850MJ/m² (approximately 3.8~4.5kwh/m²). Equivalent to the combustion heat of 140~180kg standard coal. It mainly covers the middle and lower reaches of the Yangtze River, Fujian, Zhejiang and parts of Guangdong, where there are rainy in spring and summer, and solar energy resources in autumn and winter are good.

2.4 Class IV solar photovoltaic resource areas

The annual solar radiation is below $4200 \sim 5000 \text{MJ/m}^2$ (approximately $3.2 \sim 3.8 \text{kwh/m}^2$). It mainly covers part of Hunan and Hubei Provinces. This is the region with the least solar energy resources in China.

In general, the annual sunshine duration of the Classes I and II areas are not less than 2200 hours, which are rich in solar energy resources in China; the Class III areas are

relatively rich in solar energy resources, and the annual sunshine duration of the Class III areas is slightly lower than those of the Classes I and II areas, so the solar resources in these areas can be developed and utilized.

It can be seen from Figure 1 that, the area of Classes I, II and III is relatively large, accounting for more than 80% of the total area of the country. At present, nearly 60% of highways in China is located in Class III areas, and nearly 30% of highways is located in Classes I and II areas. In general, there are good solar photovoltaic resources along the highways in China, which have favorable conditions for development and utilization.

3 Solar pavement construction scheme

According to the solar pavement construction plan, three technical modes can be used in China's highway photovoltaic power generation:

First, regional solar energy utilization technology for management and service facilities. The solar photovoltaic power generation system will be built mainly in service areas, toll stations, parking lots, management centers and large filling slopes along the highway.

Second, solar photovoltaic corridor technology for energy concentration point of highway tunnel entrance and exit. The highway tunnel has the largest demand for electricity because of concentrated electricity facilities. Making full use of the entrance and exit of the highway tunnel, overhead solar photovoltaic power generation corridors are established at the entrance and exit of the tunnel. On the one hand, the equipment in the tunnel is powered by photovoltaic clean energy, and the remaining power can be connected to the grid; on the other hand, the photovoltaic power generation corridor at the entrance and exit of the tunnel can effectively alleviate the visual stimulation of "black hole" and "open hole" when entering and exiting the tunnel, and can be used as a brightness buffer to meet the dark and bright adaptations of the human eyes due to changes in light intensity. Time buffer needs to improve the safety and visual comfort of the entrance and exit of the tunnel.

Third, solar pavement technology based on photovoltaic power generation. At present, solar pavement is a new type of pavement structure and materials in a new research and development direction. Compared with the traditional road surface, it should not only meet the requirements of vehicle bearing performance, road performance, safe driving, but also meet the photovoltaic power generation demand.

Combined with the current status and development trend of highway + solar energy clean energy technology, the future construction plan of highway + solar energy in China mainly includes the following three aspects:

(1) Develop solar energy fully relying on optimized highway pavement space, three-dimensional space and other road network linear areas; construct solar-powered pavements, solar photovoltaic slopes and solar photovoltaic corridors along the road network; create solar highway linear energy flow (as shown in Figure 2).



Fig. 2. Solar highway linear energy flow

(2) Develop and utilize regional power generation systems such as solar parking lots, solar buildings and solar lighting in the management centers, service areas, toll stations and other large-scale centralized power consumption areas along the highway with its space and ground resources, so as to create regional power source and flow of solar energy (as shown in Figure 3).



Fig. 3. Solar highway regional energy flow

(3) Develop and utilize solar tunnel entrance and exit photovoltaic corridors, solar service area buildings and distributed regional power generation systems at highpower energy equipment points in tunnels along highways, so as to create regional energy flow of solar energy (as shown in Figure 4).



Fig.4. Solar highway regional energy flow

(4) Build solar energy expressway micro-grid control system, and connect electricity from green energy sources to the grid nearby, creating a three-dimensional solar pavement clean energy network combining "points, lines and regions". Provide green energy for a large number of electric facilities and equipment along the highway as well as surrounding cities and villages.

The combination of "highway + solar energy" concept in the future, will integrate the traffic flow, people flow, logistics, clean energy flow and intelligence functions of the highway, to create a new generation of highway with the integration of transportation network, information network and energy network.

4 Benefit analysis of solar pavement photovoltaic power generation

According to the 101 standard defined by the European Commission, under the radiation intensity of 1000W/m², the air mass of AM1.5, and the battery temperature of 25°C, professional calculation software is adopted to calculate the daily average power generation per square meter (based on Class III areas with 7 hours of available daylight during the daytime), the cost of monocrystalline silicon is calculated according to 2.8 yuan /W, and the results are as follows.

The cost of solar photovoltaic power generation after completion is about 1.74 yuan/kWh. In 2016, the average electricity price of coal power in China was 0.36 yuan/kWh, considering the environmental cost (0.56 yuan/kWh). The cost of solar photovoltaic power generation system is 1.38 yuan higher per kilowatt hour. However, the construction cost of a solar photovoltaic system is a one-time investment for hardware facilities, and the power generation is green and cost-free within the 5-10 year life cycle (except for partial maintenance expenses), generally, the one-time investment in the construction of photovoltaic power generation system can be recovered in 2-3 years.

If the above solar energy highway construction scheme can be implemented on ordinary roads in Classes I, II and III areas in China, the scale and amount of electricity that can be generated annually from clean energy sources is even more noticeable.

4.1 Economic benefit analysis of solar photovoltaic pavement

Taking highway emergency lanes laying solar-powered pavement as an example, emergency lanes of 131,000 kilometers of highways (it is conservatively estimated according to the resources of Class III, the width of the emergency lane is estimated at 2.5m) are paved with solar power: the average annual electricity production is about:

1.23 kilowatt hour/m²/day × 13.1 × 104 × 103m × 2.5m (area) × 180 days (average annual effective light days) \approx 7.5 × 1010 kilowatt hour. I.e.: it can generate more than 70 billion kilowatt hour of solar energy per year.

4.2 Economic benefit analysis of solar photovoltaic service area

Taking the highway service area as an example (the available area is conservatively estimated to $600m^2/50km$ for 2 service areas), the daily average power generation is about (it is conservatively estimated according to the resources of Class III):

1.23 kilowatt hour/m²/day × 2720 service areas × $600m^2$ /service area× 180 (average annual effective light days) $\approx 3.6 \times 108$ kilowatt hour. I.e.: it can generate 360 million kilowatt hour of solar energy per year.

4.3 Economic benefit analysis of solar photovoltaic at highway tunnel entrance and exit

131,000 kilometers of highways. The number of highway tunnels in Class I, II and III areas is conservatively calculated as 100 tunnels and 2 lanes in one direction, each tunnel has 4 entrances and exits in both directions, the construction length of each monocrystalline silicon solar photovoltaic corridor is 100m:

1.23 kilowatt hour/m²/day ×(4×100) m×7.5m/tunnel ×100 tunnels× 180 (average annual effective light days) $\approx 6.6 \times 107$ kilowatt hour. I.e.: it can generate more than 60 million kilowatt hour of solar energy per year.

4.4 Economic benefit analysis of solar photovoltaic on highway slope

Roadside lower slopes along the highway can be used. It the lower slope available per km on both sides is calculated as 100 square kilometer ($100m^2/km$), the areas along the line are all measured in accordance with Class III, and the power generation is about:

1.225 kilowatt hour/m²×100m²/km×13.1×104km \approx 172 million kilowatt hour.

5 Conclusions

Power consumption runs through the whole process of highway construction, operation and maintenance. For highways, in addition to the large-scale power demand of construction facilities and equipment during the construction, it is also the long-term large-scale power demand for a large number of distributed facilities and maintenance equipment along the line during operation. According to rough statistics, the power consumption of highways accounts for about 60% of its operating costs, especially the highway section with many bridges and tunnels, the electrical energy costs account for a larger proportion of the operating costs. The construction of solar-powered highways can first meet their own power consumption needs, and can also supply and output power through grid connection, transforming the road transportation industry from a traditional energy consumption industry to an energy supply industry. In the new era, Chinese highways have gradually shifted from the construction stage to the smart transportation development stage focusing on improving public travel service levels, improving transportation management efficiency, improving traffic safety, and promoting intelligent transportation infrastructure management. A large number of road network operating state perception, collection, communication, analysis, processing and release facilities and equipment need to be added to support the realization of smart roads and smart transportation functions. The power demand along the highway is larger and the power supply points are more dispersed. Therefore, the solar highway pavement can provide a clean energy channel for a large number of power facilities and equipment along the line to meet the huge growth demand of smart highway power. The construction of solar highways develops the highway from a simply consumer dependent on external energy supply to a clean energy self-sufficiency and energy gridconnected supplier, which is conducive to reducing costs and increasing efficiency in the road transportation industry. This will promote the faster development of China's fifth-generation highway based on energy structure optimization, green transportation and smart transportation, and make industry contributions to the development and utilization of national clean energy to help the construction of a beautiful China. Moreover, the large-scale development of solar pavement will also digest the remaining capacity of my country's photovoltaic industry in a large amount and support the development of my country's photovoltaic industrialization.

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