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The Optimized Solar-Powered LED Lighting System in Gas Stations

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Abstract: In accordance with the specifications for the design of the gas station lighting system, the original lighting system was transformed into the overall solar-powered LED lighting system. The original lighting was replaced by using the same illumination LED lamps. Calculations were made to determine the optimum tilt angle of solar components. Based on the reasonable LOLP rate, solar module and battery capacity were also measured. Conductance increment algorithm was employed to achieve the tracking of photovoltaic cells on the maximum power point. The solar LED lighting system could be automatically switched seamlessly with the general municipal power, featured with superior explosion-proof performance, protection performance and a significant energy-saving effect.

Keywords: LED lighting system, MPPT, photovoltaic system.

1. INTRODUCTION

CNPC currently has some 18,000 gas stations, which may consume a lot of energy on lighting services. If calculated according to the full-load lighting at every gas station, the power consumption may reach 25,000 kwh per year, then the CNPC with all the power stations could have reached a staggering annual value of 450 million kwh. Thus, the transformation of the gas station using solar LED would be able to bring about huge economic and social benefits [1, 2].

The lighting system is designed with a transformation program that is based on Standardized Design for the Gas Station Construction, Specifications for Design and Construction of Vehicle Refueling Stations (GB50156 - 2002) (Edition 2006), Architectural Lighting Design Standards (GB50034 -2004), Standards for the Public Building Energy Efficiency Design (GB50189-2005), Standards for the Gas Station Construction of China Gas Co., Standards for the Gas Station Construction of China's Sinopec, with the roadside type of gas stations (Class II) as reference objects. The original lighting system was replaced by a solar-powered LED lighting system.

The whole system was comprised of the photovoltaic cells, lead-acid batteries, sine wave inverter, mains hybrid controller and LED lighting. PV controller is responsible for the regulation and control of DC generated by the battery components: on the one hand, the adjusted and inverted DC was supplied to the LED lamps; on the other hand, the excess energy was sent to the batteries for storage, and automatically switched to electricity supply in the cases of the battery charge coming too low [3]. The system is illustrated in Fig. (**1**).

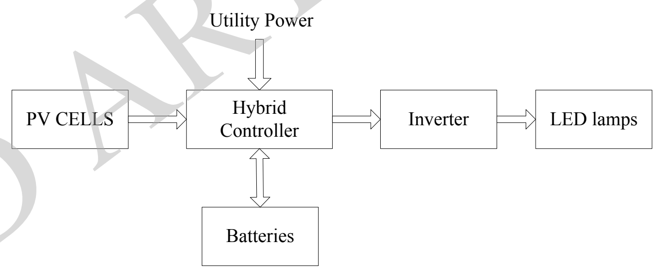

Fig. (1). Structure of the solar LED lighting system.

2. TRANSFORMATION OF LAMPS

The general principle for the transformation is to use the LED lamps of the same illumination to replace the original lamps. Design standards include two different rules for different forms of lighting situations: (1) directly giving the type of lighting, power, number and arrangement, such as the canopy lighting; (2) giving the illumination area, such as refueling area lighting. In the first case, the formula is expressed as

$$P_2 = \frac{P_1 K_1}{K_2} \tag{1}$$

Here, P_1 is power of original lamp, P_2 is LED lighting power, K_1 is luminous efficacy of the original lamps, and K_2 is luminous efficacy of LED.

For the second case, lighting configuration was subjected to the ratio 1.1 of the work area and the adjacent work area, taking the intermediate values of illumination standard values, using the formula:

$$P_2 = \frac{EA}{2K_2} \tag{2}$$

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Here, E is the intermediate value of illumination standard value, and A is the size of work area [4, 5].

Lighting fixtures located in the area of gas stations, after calculation, were replaced with LED lamps of equal intensity, being summarized as the Table **1**.

Table 1. Summary of LED Lighting Fixtures at Gas Station.

Lighting Area	LED Lamps			
	Lamps	Power (W)	Qty	Sub-Total of Power (W)
Canopy surface	LED Module	1.2	870	1044
Refueling area	LED Bay Light	120	12	1440
Station house	LED Light Tube	12	38	456
Main signage	LED Light Tube	18	50	900
Tank area	LED Bay Light	120	1	120
Total				3960

3. DETERMINATION OF THE CAPACITY OF PHOTOVOLTAIC CELLS AND BATTERIES

The photovoltaic cells and batteries capacity have to ensure the total power of 3960 W LED lamps. In sunny days, the batteries can be fully charged all day, and in the fully open state, available for the continuous illumination lamps up to 36 hours of lighting duration.

Ningxia region, where the gas stations are located has the average number of sunshine per day 5 hours to be considered. The DC voltage was designed upon DC220 V, battery depth of discharge coefficient of 0.75, taking 93% of inverter efficiency.

Determination of the combination of solar and battery capacity requires that on the premise of ensuring the load reliability of street lights, the least solar components and battery capacity are placed to achieve the best combination of reliability and economy in the most optimal design [6, 7]. For the reliability measurement, the Loss of Load Probability (LOLP) is mostly used at home and abroad. It is defined as the ratio of the system outage time and the power consumption time. LOLP value is between 0 and 1, the smaller the value, the higher the reliability. Reliability requirements should be set with some limits in the design of solar LED lighting systems. In addition to meet the load reasonable reliability, the best economy should be guaranteed. The solar LED lighting system design is given an LOLP value of 0.1 for its reliability to ensure the three rainy days supply. According to this reliability design, the system configuration is as shown in Table **2**.

Table 2. Configuration of the solar LED lighting system.

Category	Parameter
Photovoltaic modules	260 Wp Silicon(150 pcs)
Battery	24 V/1200AH Series (10 pcs)
Sine wave inverter	240 V/10KVA
Utility power hybrid controller	220 V300 A

4. DETERMINATION OF THE BEST ANGLE OF THE PV ARRAY

Due to cost constraints, non-concentrating PV modules do not involve the use of dual-axis tracking agencies to ensure the maximum power output, so during installation, it is a obligatory to determine the best angle of the PV array. Comprehensive consideration is given to the tilted square face with regard to the annual radiation continuity, uniformity, and maxim, and then the sky diffuse radiation anisotropic model was employed for calculating the amount of radiation on the tilted surface:

$$H_T = H_b R_b + (H - H_b)[\frac{H_b}{H_o} R_b + (1 - \frac{H_b}{H_o})\cos^2\frac{\beta}{2}] + \rho H \sin^2\frac{\beta}{2} \quad (3)$$

$$R_b = \frac{\cos\theta_i}{\cos\theta_z} \quad (4)$$

$$\theta_i = \cos^{-1}[\cos\theta_z\cos\beta + \sin\theta_z\sin\beta\cos(\gamma_s - \gamma)] \quad (5)$$

$$\theta_z = \cos^{-1}[\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega] \quad (6)$$

$$\gamma_s = \sigma_{ew}\sigma_{ns}\gamma_{so} + \left[\frac{1 - \sigma_{ew}\sigma_{ns}}{2}\right]\sigma_w 180^\circ \quad (7)$$

$$\gamma_{so} = \sin^{-1}\left[\frac{\sin\omega\cos\delta}{\sin\theta_2}\right] \quad (8)$$

$$\sigma_{e\omega} = \left\{\begin{array}{cc} 1 & |\omega| \le \omega_{e\omega} \\ -1 & others \end{array}\right\} \quad (9)$$

$$\sigma_{ns} = \left\{\begin{array}{cc} 1 & \varphi(\varphi - \delta) \ge 0 \\ -1 & others \end{array}\right\} \quad (10)$$

$$\sigma_{\omega} = \left\{\begin{array}{cc} 1 & \omega \ge 0 \\ -1 & others \end{array}\right\} \quad (11)$$

$$\omega_{e\omega} = \arccos(\frac{\tan\delta}{\tan\varphi}) \quad (12)$$

Here, H and Hb are the horizontal surface solar radiation and direct radiation; Rb is the ratio of direct radiation on the inclined surface and that on the horizontal surface, Ho for the amount of solar radiation on the horizontal surface outside the atmosphere, β for the square angle, ρ for the surface reflectivity, θi for the incident angle, θz for the solar zenith angle, α for the sun elevation angle, γ for the surface azimuth angle, γs for the solar azimuth.

Based on the calculation of the above model Hay, Gas Stations in Yinchuan had set up the PV array inclination of 42°, so we could get the most amount of light on the bracket of an invariable angle for the whole year.

5. TRACKING ON THE MAXIMUM POWER POINT

The output characteristics of photovoltaic cells are subjected to light and temperature, where the migration of the system operating point may lead to the decline of the system efficiency. Due to this, there is a need for the solar arrays to achieve the tracking control over the maximum power point, so that at any light intensity and ambient temperature, solar arrays are able to get the maximum power output.

Considering the sunshine conditions of Ningxia region where stations were located, the incremental conductance method was introduced to achieve the maximum power point tracking. As solar cells had an invariable light intensity, the PV system output could be stabilized at the maximum power point. When changes occurred in light intensity, the PV system output could smoothly follow the changes, limited to a smaller range of voltage disturbances. And this control method is featured in a quicker response time, and able to adapt to rapid changes in light intensity (Fig. **2**).

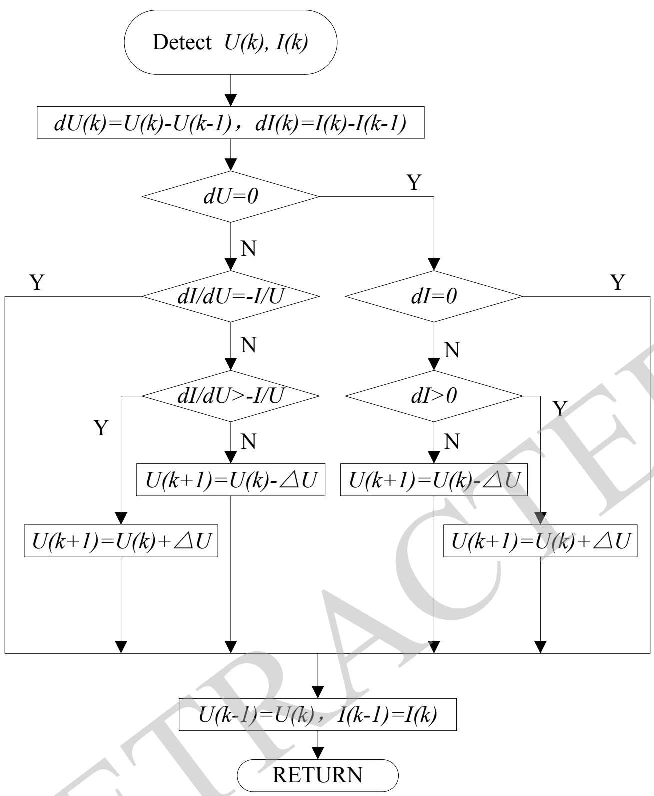

Fig. (2). Flowchart of the incremental conductance method.

PV photovoltaic cells provide the power curve with a slope of zero at the point of maximum. Then:

$$\frac{dP}{dU} = \frac{d(UI)}{dU} = U\frac{dI}{dU} + I = 0 \quad (13)$$

$$\frac{dI}{dU} = -\frac{I}{U} \quad (14)$$

From the above equation, reaching the maximum power point is subjected to the condition that the change in output conductance is equal to the negative value thereof.

CONCLUSION

According to local climate conditions of Ningxia, the original lighting system of the gas station was overall transformed into the solar LED lighting system. Its design was strict in compliance with specifications on the design the lighting system of gas stations. Combined with the characteristics of solar photovoltaic power generation, the entire system was optimized to achieve the tracking of the maximum power point of photovoltaic cells, improving the utilization of solar panels. The system can automatically switch seamlessly with ordinary utility power, featured with superior explosion-proof performance, excellent protection performance, and a significant energy-saving effect. After nearly one year of the actual test observation, solar LED lighting system shows results that are consistent with design requirements. After three days of consecutive cloudy days, the lighting system can still work not relying on the utility power supply.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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