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Research Article
Design of a Power Management in Wind/Solar Hybrid Street Lights Network

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Abstract
Background and Objective: Solar and wind energy are inexhaustible, clean, renewable and environmental friendly. As the global climate issues are increasingly serious and the energy crisis is continually growing, the use of solar and wind energy has become a current and future focus of study and application. **Materials and Methods:** This study provides a solution design of a hybrid street lights network power management, the way of making street light in network and sharing the rich energy of network street light with others through power line carrier communication, it designs a set of active-passive mode energy sharing method based on three-level electric quantity threshold value algorithm. **Results:** Under the premise of solar energy abundance in some street lamps, the project share the excess solar of the street lights to other lights. It also solves the problem of insufficient energy in node of part of street lights in the area caused by uneven illumination and temporary shelter. **Conclusion:** Experiments shows that it enhances regional solar/wind overall utilization of the greatest lighting needs and also extends the life of the battery.

Key words: Street light networking, solar power, wind power, sharing three-level liminal value, active-passive mode energy

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INTRODUCTION

Solar and wind energy are inexhaustible, clean, renewable and environmental friendly. As the global climate issues are increasingly serious and the energy crisis is continually growing, the use of solar and wind energy has become a current and future focus of research and application[1-7].

As solar power (Wind) technology matures, solar and wind energy can efficiently match to form a wind/solar complementary systems, the combination between hybrid energy systems and energy-conscious LED lighting systems will be the focus of development and universal access and also become an effective solution for the global and national responses to climate change[2,8-10].

Due to geographical differences, off-grid areas, such as the border post, remote and mountainous region, etc., mains are difficult to supply. Hybrid power solution is undoubtedly the best lighting solutions program. Solar energy on the other hand has all the opportunity to take over the existing power generation system[5]. How to achieve the energy efficiency and take full advantage Hybrid energy to power LED will become the focus of the study. So far most solar LED lighting systems run independently and cannot share energy among themselves[6,7].

The battery serves as a hybrid lighting energy carrier. The charging ways affect its charging rate and battery life. Some scholars believe that a three-stage charging can effectively improve the utilization of solar energy efficiency[3,4,11-15]. Solar controller maximum power tracking technology promotes the solar charging speed[16-18]. The above-mentioned studies are beneficial to promote the solar energy utilization efficiency of the independent running street lights.

Fu[19] stated that most of the solar wind power street lights run independently unrelated to each other, they cannot process communicate scheduling or energy-efficient sharing or status monitoring controls. The settings of the lights are easy to blocked, for example: The setting in buildings, mountains or between when the lights under cloud untimed masks or changes in wind direction and other reasons. It often gives rise to street lights battery charge, which cannot meet the lighting needs. In order to solve this problem, some studies[20-22] suggest networking the solar/wind powered street lights and mains. When the supply of the solar/wind is insufficient, it can be complemented by the mains. In solar utilization field, some researchers have studied grid-connected inverter problem[23-25], whereby connecting the renewable solar energy and wind power to distribute network to supply mains. However, few have studied how to process the energy complement and the scheduling within the hybrid street lights area, under the condition of inconvenient supply from mains.

In Wu Feng's "Solar wind power integrated high intelligent control method and its system"[26], he designs to network the solar/wind hybrid powered street lights. After the battery of street lights in the network is fully charged, the excess solar of the street lights can be shared to other lights. But, in most cases the light's power consumption at nights is less than the power of the fully charged battery. Meanwhile, there is wind energy at night powered for battery. Therefore, the utilization rate of solar/wind energy in this design is not high.

In order to solve the technical problem that some street lights which can't offer power normally in the area caused by the lack of solar/wind and that the sufficient solar/wind energy can't be best used of adjacent street lights and that solar/wind energy utilization rate is not high, this study puts forward a new power management design solution in the network of wind/solar complementary street lights.

MATERIALS AND METHODS

System overall frame: The design solution of power management in the network of the hybrid street lights in this study includes hardware and software design. Based on the active-passive mode energy sharing method of three-level electric quantity liminal value, the software solution includes the active and passive sharing solutions.

By detecting battery charging quantity, the street light control system compares with preset three-level liminal value.

When the solar and wind energy is sufficient, the battery charge level C is greater than the maximum power liminal value C_H. The lights are under the action of the controller, then the power line carrier module sends a broadcast message to notify other street lights and simultaneously turns on the inverter and shares the excess energy to other lights by power lines. Street lights, which need to share energy then connect to AC charging unit and charge to the battery. In this way the street lights network access active energy sharing mode.

When solar and wind energy is insufficient, the battery charge level C is less than the minimum power liminal value C_L. The power line carrier module sends a broadcast message to notify other street lights that it needs other street lights to

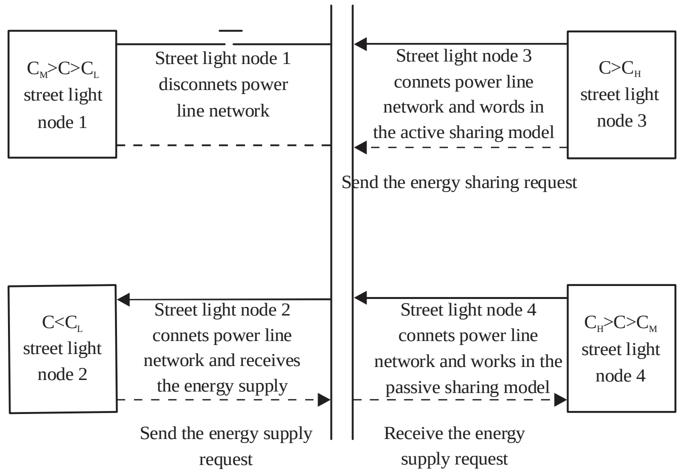

Fig. 1: Street light network model

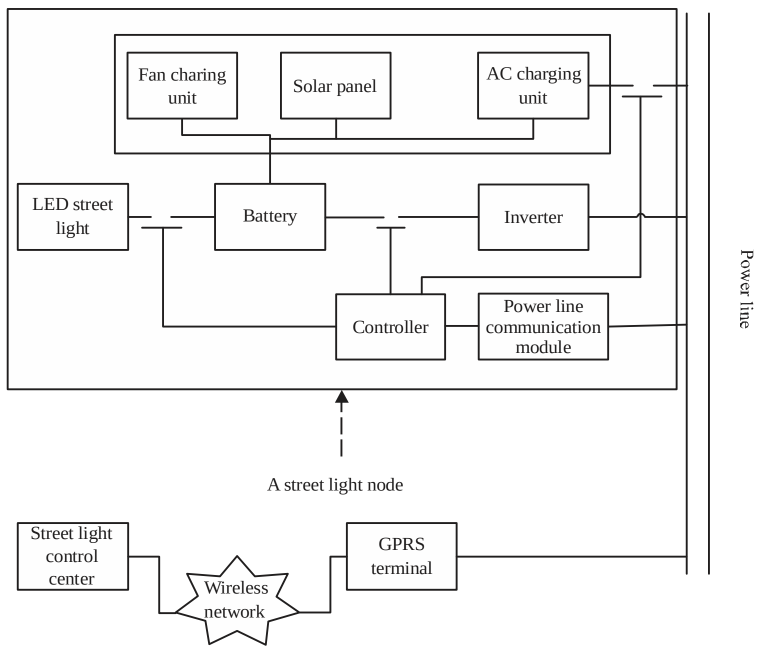

Fig. 2: Hardware structure diagram of street light network

offer energy supplements. It connects to AC/DC controller and waits for other street lights to share the energy and charges to battery through power line. If battery's power level C is larger than C_M, street lights connect to the inverter by using the power line to share spare energy with other street lights. The streetlights network access passive energy sharing mode.

Figure 1 shows C is for the charging capacity of street light. The C_H, C_M and C_L is three-level electric quantity liminal value from high to low. The solid lines are for the current line. The dotted lines are for the broadcast information line.

Hardware design: The network of street lights is composed of several street light nodes, each of which includes light-emitting device, storage battery, controller, solar panel, fan charging unit, inverter, AC charging unit and power line communication module, etc. The hardware structure diagram of street light network is as shown in Fig. 2.

Street light controller: Controller realizes the intelligent control of street light, controlling battery to chooses the charging way of solar, wind or AC current, controlling whether the solar and wind power of street light node inverts to the power line network and controlling the communication management of the street light network. Controller processor adopts MSP430 MCU.

Charging/inverter circuit: The solution applies three charging ways for the battery of street light: Solar charging, fan charging and AC charging.

Solar battery charging control adopts detection interference method[18] of maximum power tracking technology. Combined with the characteristics of the battery, it divided into three phases: MPPT charging mode and constant pressure filling mode, constant voltage floating mode[7,15]. The controller chip adopts TMS320F280200.

Fan charging unit, which controls wind energy to the battery, makes hybrid excitation permanent magnet synchronous generator to apply for wind turbinesystem. The hybrid excitation permanent magnet synchronous generator combines the advantages of EESG and permanents magnetsynchronous generator, which offers constant voltage through adjusting the exciting current in the power occasion of variable speed or unstable load. The maximum tracking[27] of wind energy can be realized by controlling exciting current of hybrid excitation permanent magnet synchronous generator to make the motor run in the best speed.

The AC charging unit transfers AC electrical power into DC electrical power to charge for battery when accepting the electrical power offered by other street lights.

Inverter: Inverter transfers DC electrical power of battery into AC electrical power when offering electrical power to other street lights and offer carrier for power line carrier communication. The inverter solution in this study is sine wave inverter[28,29] as shown in Fig. 3. To guarantee the communication quality, this inverter adopts closed-loop feedback way to adjust inverting signal.

Communication module: Power line communication module adopts the power carrier agreement to realize the communication of control network system between street lights. Power line module is connected via the serial port and controller[30].

GPRS terminal: One GPRS terminal is set and used in one street light network. Each GPRS connects to and communicate with the control center, by which it collects the fault report of street lights and time management of the lights.

Software design of active-passive mode energy sharing method based on three-level electric quantity liminal value: Based on the active-passive mode energy sharing method of three-level electric quantity liminal value, it adopts the both active and passive energy sharing mode. Every street light contains three default power value, which are C_H, C_M and C_L from largest to smallest, respectively. The calculation formula is as follows in Eq. 1-3:

$$C_H = T_N \times P \tag{1}$$

$$C_L = T_S \times P \tag{2}$$

$$C_M = C_L + E_L + E_D \tag{3}$$

where, T_N is for the lighting time at night. The T_S is for the remaining lighting time at night. Because the lighting time of the winter is different from that of summer, T_N and T_S value are dynamic. The P is for the power of street light. The C_H value is the electricity consumption of street lights in the whole night lighting, as the liminal value of active sharing energy with street light network, C_L value is electricity consumption of lighting for remaining time at night, as the liminal value of asking street light network for energy supplement. The C_M as the liminal value of sharing energy with street light network actively. The E_L is the energy loss for DC energy to invert into DC. The E_D is the energy loss it brings in the process of transmission. The output voltage of solar panel is V_P and V_B is the battery voltage on both end.

When power value of the battery C is larger than CH, it can share its available solar/wind power with other street lights in the network. On the basis of guaranteeing its own energy need, it shares its own energy with other street lights in the network actively. In this way, it ensures that the electric quantity of battery of more street lights in the network can meet the need of lighting at night. This is active sharing mode.

When power value of the battery C is less than C_L, it sends power supply request to other street lights. By this way, it avoids the case that power of this street light is insufficient. When power value of the battery C is greater than the C_M, it judges whether it receives power supply request of other street lights. When, it receives power supply requests of other street lights and while, the fan unit or solar panel is charging for battery at this time, it offers power to the street light, which send power supply request. This is a passive sharing mode.

In the case of sufficient light intensity ($V_P > V_B + 1$), it adopts active sharing energy mode. The method and process is as below:

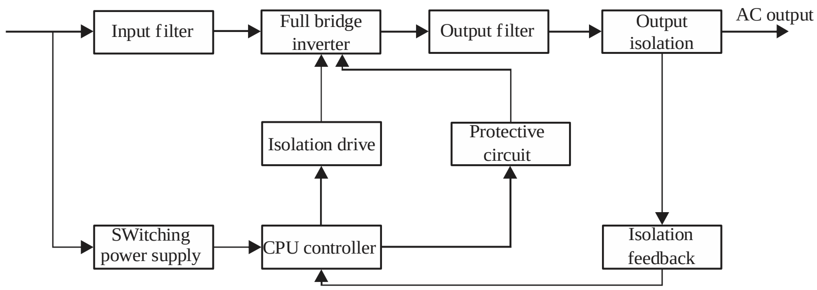

Fig. 3: Inverter internal structure

- When power value of the battery C is greater than C_H value, the controller of street lights sends sharing broadcast messages to street light network
- The street light controller connects to inverter and gets ready to share energy with street light network
- When the electric quantity of battery C is less than CL, the street lights receive the broadcast messages of sharing energy and connect to inverter
- When battery power value C is greater than C_H value, through the street light network, the street lights share energy with the street lights whose power value C of battery less than C_L value

In the case of insufficient light intensity (V_P<V_B+1), it adopts passive sharing energy mode. The method and process is as below:

- When power value of the battery C is greater than C_L value, the controller of street lights sends supplement energy broadcast messages to street light network
- The street light controller connects to inverter and gets ready to share energy with street light network
- When the electric quantity of battery C is larger than C_M, the street lights receive the broadcast messages of supplement energy requests and connect to inverter
- When battery power value C is greater than C_M value, through the street light network, the street lights share energy with the street lights whose power value C of battery less than C_L value

RESULTS

Experiments settings: In order to verify the effectiveness of this solution, the system has been applied in Wanlida industrial park, Bao'an district, Shenzhen. The verification test took 2 years. For contrast test, 16 street lights were installed in the industrial park, including 8 pcs for independent installation and other 8 pcs, which are adopted network methods proposed in this study. The test area is located in East longitude 113.6°C and North latitude 22.5°C. The test adopts street light with 30 W power, 120 W solar panel and 200 AH battery capacity.

In contrast test, two properties of this solution are tested: Street light bearing continuous rainy days, the influence of battery life.

For the change of battery life, it adopts discharge capacity of traditional battery to test. Discharging equipment is used in full charging state to discharge for battery and test the discharging capacity of the battery. Its calculation formula is as shown in Eq. 4:

$$C_A = C_M/C_F \quad (4)$$

where, C_A is for discharging capacity (percentage), C_M is for the largest discharging capacity of battery, C_F is for full charging capacity of battery. The light hours of test area is as shown in Table 1.

Experimental analysis: After two year's operation, especially in the time from November-March when the lighting hours are insufficient. The street lights, which operated independently can continuously work on 6 rainy days, while the solar street lights in network method proposed in this study can continuously work on 10 rainy days. It shows that street light's ability of bearing rainy days are greatly improved.

To test how network method proposed in this study impacts the battery life, after 1.5 year's operation, the full charging on battery for 16 pcs street lights is proceeded every other month. And discharging ability of battery is tested by using discharging equipment (the percentage of full charging capacity). The data of 8 pcs independent running lights are as shown in Table 2, the data of 8 pcs running street lights in network are as shown in Table 3.

Figure 4 shown that in with the combination of above data, it can be found that the discharging ability of battery by running for 1.5 years is obviously superior to independent

Table 1: Area lighting hours

Months	1	2	3	4	5	6	7	8	9	10	11	12
Lighting hours (h)	3.02	2.78	3.03	3.63	4.24	4.53	4.96	4.63	4.35	4.22	3.79	3.25

Table 2: Discharging ability of battery for independent running street lights (DL)

Street light code (%)	1	2	3	4	5	6	7	8
First test result	92.4	90.0	92.1	90.4	92.8	91.7	91.4	92.5
Second test result	92.1	90.8	91.8	90.1	92.0	92.0	91.2	91.0
Third test result	92.6	89.8	91.6	89.6	91.0	91.6	89.8	90.8
Forth test result	91.8	89.6	91.7	88.0	91.6	91.5	89.6	90.4
Fifth test result	91.6	89.0	91.6	89.2	91.4	90.2	89.4	90.4
Sixth test result	91.3	88.5	90.8	88.9	90.8	89.6	88.9	90.2

Table 3: Discharging ability of battery for running street lights in network (OL)

Street light code (%)	1	2	3	4	5	6	7	8
First test result	94.1	91.5	94.2	91.6	91.2	92.8	93.6	94.4
Second test result	94.3	91.0	94.0	91.4	91.3	92.5	93.7	94.7
Third test result	94.0	91.4	93.8	91.3	91.0	92.1	93.3	94.1
Forth test result	93.8	91.5	93.9	91.4	91.1	92.3	93.2	94.0
Fifth test result	93.9	91.2	93.8	91.2	91.0	92.0	93.0	93.8
Sixth test result	94.0	91.0	93.8	91.4	90.8	91.8	92.5	93.5

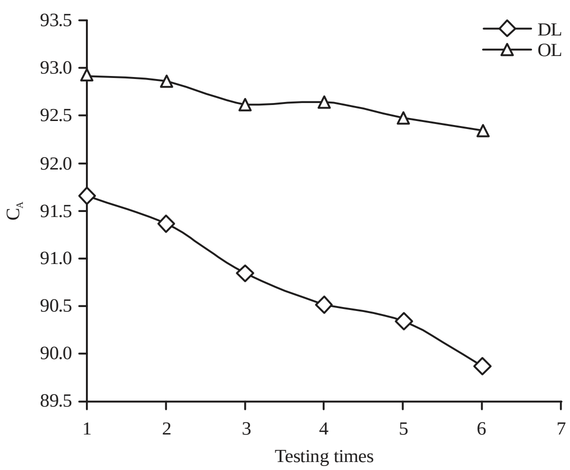

Fig. 4: Independent running street light (DL) and running street light in network (OL)

running street lights. Meanwhile, the 0.5 years test found that discharge capability change of network lights is less than independent running lights.

DISCUSSION

Most solar LED lighting systems[6,7], which run independently can continuously work only on 6 rainy days and cannot share energy among themselves. Solar utilization is not high. In Wu Feng's solar wind power integrated high intelligent control method and its system[26], the electric quantity threshold value is fixed. Excess energy is not enough to use. As shown by the above results, the project which adopts stree tlights network and active-passive mode energy sharing method based on three-level electric quantity threshold value algorithm has improved the ability of bearing continuous rainy days and battery life, than the street lights, which operated independently and Wu Feng's solar wind power integrated high intelligent control method and its system.

CONCLUSION

This design solution of power management in hybrid street lights network is a way of networking the single node of street light and sharing the energy based on active-passive mode energy sharing method of three-level electric quantity liminal value. It greatly improves the utilization rate of solar/wind energy and saves the cost of power; it greatly improves complementary of the wind energy and solar energy and makes reasonable use of natural resources. It does play an indispensable role in lighting between the urban roads and building. The system in a great degree gets the available energy in network to charge for the other street lights with insufficient energy, which brings some advantage for maintenance of battery. Meanwhile due to its intelligent adjustment by the control system, it can greatly reduce the waste of human recourse. Therefore, this solution is worthy of high advertisement and application.

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