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Photovoltaic Technology and Electricity Saving Strategies for Fixed-Velocity-Measuring System

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Abstract

The power supply methods for fixed-velocity-measuring system (FVMS) based on photovoltaic (PV) technology are proposed after analysis and comparison among the current methods for FVMS on freeway. According to the sunshine condition in typical low sunshine areas, all components consist of PV system are specially designed, including the related maximum power point track (MPPT) technology for solar panel and the charge-discharge algorithm for storage battery in the dedicated controller. Targeted electricity saving strategies for FVMS on freeway are put forward. Experimental results show high efficiency and stability of the dedicated controller and in practical application, the specially designed PV system in this paper can provide continuous electric power supply throughout a year in an efficient way, and the output voltage and frequency are stable.

Keywords: *photovoltaic technology (PV), MPPT, charge-discharge algorithm, fixed-velocity-measuring system (FVMS), electricity saving strategies*

1. Introduction

The fixed-velocity-measuring system (FVMS) on freeway can effectively detect the traveling vehicles' velocity and send feedback to the law enforcement and monitoring center timely and accurately, so as to urge drivers to control their speed, consequently decrease the accident rate. It is a premise to keep effective, everlasting and stable power supply for functions' realization of FVMS.

1) Analysis of the current power supply methods for FVMS

Nowadays, there are two major modes for FVMS' power supply –electric supply and solar power.

Electric supply is the primary mode. While, the mains voltage fluctuates heavily and frequently exceeds the requests of equipments consist of FVMS, that makes not only electrical energy waste but immensely shorten FVMS' lifetime. Especially for the remote and inaccessible core parts of freeway to electric supply, electric wire construction, system maintenance and repair need a huge expense, moreover, the electrical energy loss during power transmission will be great [1].

Solar power supply is to build an independent PV system to realize FVMS' electric power supply. Firstly, solar energy resource is inexhaustible and PV system can be easily established as long as the solar illuminance and geographical conditions are suitable. Secondly, the output of PV system is stable DC which can meet all equipments' requirements for supplied voltages and frequencies in FVMS through DC-DC and DC-AC conversion. Thirdly, compared with electric supply, solar power supply is more effective and the stable output voltage and frequency can effectively prolong FVMS' lifetime. Moreover, selection of the installation sites are flexible, and system construction and maintenance need less cost; additionally, PV system has a higher safety level and lower resource occupation rate; and so on [2].

2) Background

With the growth of global energy demand, increasing consumption of non-renewable resources such as coal, oil, natural gas, etc, and environmental pollution, exploitation of solar energy becomes more and more important for our human beings. It is estimated that one-day solar radiation reaching on the earth can supply enough energy to the currently existing 6.5

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billion populations at present consumption rate for more than 26 years [3]. Based on the photoelectric effect, PV technology which converts solar energy into electrical energy is clean, safe, long-lived, widely applicable, and free to maintenance. There are plenty of natural resources available; as one of the most important technologies to utilize solar energy, PV technology surely will have enormous potential economic and social value [4, 5].

Chongqing, located beside the north and south climate boundary of our country, is the intersection of cold and warm air, and most of a year there is less sunlight and more rain here. Along with Sichuan and Guizhou, Chongqing belongs to the 5th-class' region in our country which has the least solar radiation in a year. In these regions, annual sunshine duration is 1000~1400 hours, and all year's solar radiation is 3344~4180 MJ/m^2 which equals to the heat generated by 115~140kg coal's burning. Presently, it is rare to use independent PV power generation system to supply FVMS on freeway, not mention to the formulation of relevant power supply strategies; what's more, there are few relevant research articles published [6].

3) Research in this paper

Depended on the practical application in the freeway of Chongqing and sunshine condition of typical low sunshine areas, a dedicated independent PV power generation system is designed and developed out, both the involved MPPT technology for solar panel and charge-discharge algorithm for storage battery in the core controller are conducted the special study and design in this paper. Based on the analysis of the structure, electric power utilization and functions of FVMS, targeted strategies for saving electricity are proposed to achieve all functions, and to get effective electricity utilization and a long service lifetime for the FVMS.

2. Design of PV Power Generation System

This PV power generation system is developed out according to the sunshine condition in typical low sunshine areas and it consists of four components-solar cell panel, storage battery, controller and load.

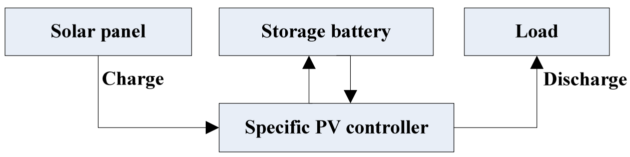

Figure 1. Photovoltaic System

1) Solar panel

Compared with single crystalline silicon solar panels, polycrystalline and amorphous silicon can effectively convert solar energy into electrical energy under low sunshine condition in daytime; by increasing the sunlight receiving area, they can get the same photoelectric conversion quantity as single crystalline silicon panels do. Polycrystalline and amorphous silicon panels have lower prices and could be more suitable for low sunshine areas such as Chongqing.

2) Storage battery

Specific PV storage battery should be the first option in practical constructions of PV system. Taking into account the daily electrical power demand of the load, maximum depth of discharge, number of days for independent functioning, and environment of the installing site, etc, maintenance-free lead-acid storage battery should be the best choice. In order to keep the balance of voltage and energy during batteries' charging and discharging, four steps must be taken in the order: First, connect every two batteries in series. Second, parallel all the series wires. Third, parallel all batteries' positive output wires together. Four, parallel all batteries' negative output wires together. After above operations, all batteries make up to a battery pack and have the common positive and negative output wire.

3) Controller

Specific PV controller is developed considering all parts' practical requirements of the PV system. First, the photoelectric conversion rate will reach to a higher level through the MPPT algorithm optimization design. Second, by making corresponding plans during different charging periods, the battery's charging efficiency and service life-time could be significantly improved, while avoiding overcharge. Third, according to the battery's voltage change in discharging, relevant strategies are made out to avoid over-discharge and make battery keep in better activity.

3. Algorithms in the Controller

1) MPPT algorithm optimization design for solar panel's charging

MPPT algorithm is applied in solar panel's charge to improve solar energy resources' utilization. The solar panel's P-V curve is non-linear; there is a maximum power point (MPP) in each P-V curve as showed in Figure 2 [7, 8]. The output voltage of the solar panel can be changed by changing duty cycle of the output current, and then make the output power export at its MPP.

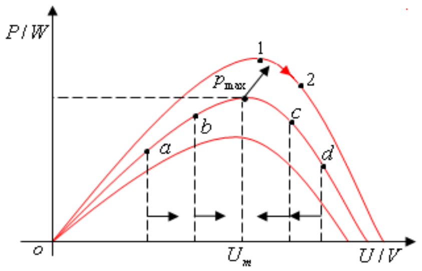

Figure 2. P-V Curve of Solar Panels

There can be the equation:

$$\frac{\partial P}{\partial V} = \frac{\partial (VI)}{\partial V} = V\frac{\partial I}{\partial V} + I\frac{\partial V}{\partial V} = 0 \qquad [9]$$

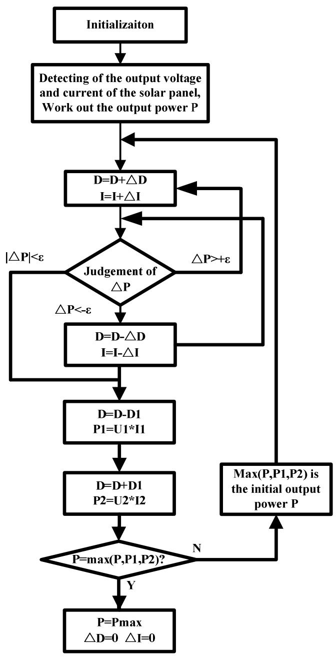

Figure 3. Flow of Successive Approximation and Disturbance Jump Algorithm

When the output power reaches to the maximum point. The flow of MPPT algorithm is showed in Figure 3. After system initialization, the PV cell's output power can be figured out by voltage and current sampling; on basis of the stable output voltage, firstly, generate a tiny change of the charging current duty cycle △D to get a tiny output current variation △I, then check the PV cell's output power variation △P (△P=P_m-P_n, P_m is PV cell's output power at this moment, P_n a moment before), depend on the above result to judge the direction var of △P and decide the next direction var of the charging current duty cycle according to the pre-set algorithm and installing space environmental factors; if the power variation △P is less than the pre-set tiny value ε, then disturb the charging current duty cycle to two greater values D_1 and –D_1 and work out the corresponding power values P_1 and P_2; then compare P,P_1 and P_2, if P=Max(P,P_1,P_2), P is the MPP, else make the Max(P,P_1,P_2) be the initial output power P of the solar panel, and step back to the start.

2) Storage battery's charging algorithm

According to the storage battery's charging current curve [10], multiple methods including pulse, constant current and trickle are used in the charging process [11, 12]. Figure 4 is the flow char of battery's charging algorithm. At the beginning of PV cell's charging, the output current is small and by using pulse mode and MPPT algorithm, PV cell's output voltage can keep in a larger value, which will greatly stimulates storage battery's activity and improve its charging efficiency, and PV cells' charging power can lies close to the MPP of the PV panel. With the charging process advancing, values of battery's voltage (V_b) and PV cells' charging current (I_s) are gradually getting larger. (V_1, V_2, V_3 and I_3 are the preset parameters) If $V_b < V_1$, still use MPPT charging method; Else compare V_b and V_2, if $V_b < V_2$, compare I_s and I_3; if $I_s < I_3$, still use MPPT charging method, else use constant current charging mode; During this period, Storage battery's voltage is lower than PV cell's and PV cell's output voltage and current are stable, in pratical, there could be the maximum amount of charge and the highest solar energy utilization. If $V_b >= V_2$, compare V_b and V_3, if $V_b > V_3$, close the charging process, else use trickle charging mode - it is the charging way when storage battery is about to saturate and by using small current's pulse charging to ensure battery's real saturation so as to prolong battery's service time.

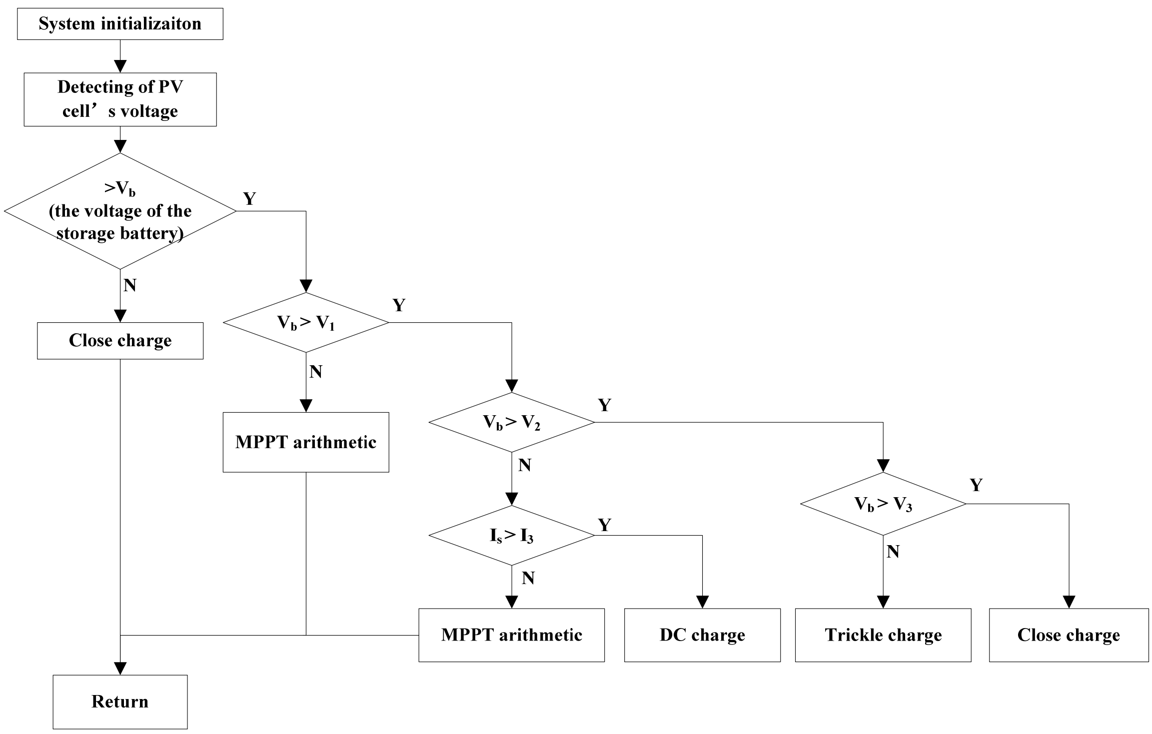

Figure 4. Flow of Storage Battery's Charging

3) Storage battery's discharging algorithm

Targeted at storage battery's discharging, there must be a planned way and operate step by step to keep the battery in good functioning state, while to avoid over-discharge. The flow char of battery's discharging is showed in Figure 5. As shown in the figure, battery's discharging voltage is processed with a hysteresis to prevent the controller frequently switching its status between charge and discharge in a short time during the discharging process to the high-power load, which could protect the controller, battery and load.

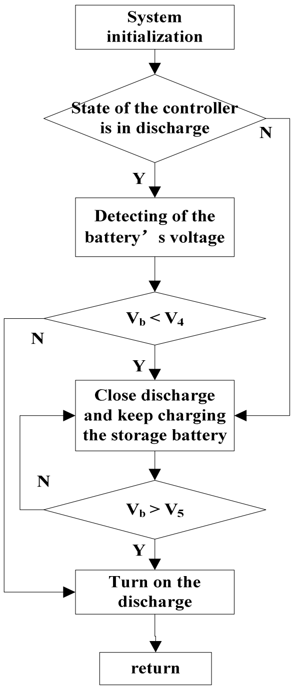

Figure 5. Flow of Storage Battery Discharging

4. Electricity Saving Strategies for FVMS on Freeway

As the load of the dedicated PV system in this paper, electrical demands of FVMS' equipments directly determine the electricity saving strategies' formulation.

The following Table 1 shows the chief equipments, power supply and functional analysis of a FVMS on Chongqing freeway.

Table 1. Chief Equipments, Power Supply and Functional Analysis of FVMS on Freeway

Equipment's name	Voltage	Frequency	Power	Function
Snap camera	DC 12V	Stable	20W	Capture the travelling vehicles' information
Smart strobe	AC 220V	50Hz	200W (the moment smart strobe is lighting)	Improve illuminance for the snap camera when vehicle's passing the FVMS
Network camera	DC 24V	Stable	20W	Shoot the road surface and synchronize the information to the traffic monitoring points
LED supplement light	DC 5V	Stable	20W	Auto open to supplement light intensity for the snap camera during insufficient light conditions
Panoramic camera	DC 12V	Stable	20W	Shoot the whole road surface
Speed measuring radar	DC 5V	Stable	2.5W	Measure the travelling vehicles' speed
Microwave radar tester	DC 5V	Stable	30W	Send out the microwave signals to vehicles installed speed measuring radar

According to the analysis of the structure, functions' realization and electrical consumption of FVMS' equipments, the following electricity saving strategies are proposed based on the dedicated PV system.

1) Adoption of DC interfaces

Operating voltages of the main equipments in FVMS are 5V, 12V and 24V, direct adoption of DC interfaces could, on the one hand, avoid the energy loss caused by conversions' comsumption of DC to AC and to DC again, on the other hand, improve system stability. If the conversion efficiency of DC to AC is 90%, and AC to DC is 90% in FVMS, the total power utilization is only 80%. In fact, the conversion efficiency between DC and AC is usually less than 90% in practical application, plus the power consumption of the converting apparatuses and the influence of the AC frequency, the cost performance of the whole FVMS will inevitably plummet.

2) Flexible light supplementing

Switches' design of smart strobes and LED supplement lights depends on the actual light intensity. By detecting the output current and charging voltage of the solar panel, the controller could judge the light intensity and time, so as to use the flexible and variable methods to make snap cameras, panoramic cameras and network cameras work at the standard light intensity. Figure 6 is the algorithm flow char for flexible light supplementing. V_6 and I_4 are the preset parameters, if the output voltage of the solar panel $V_s > V_6$, it represents the FVMS doesn't need LED supplement lights operate; and if the charging current $I_s > I_4$ while the battery is in charging ($V_b < V_{max}$, V_{max} is the maximum voltage of the storage battery) or $V_b >= V_{max}$ (close the charging process at this moment, I_s = 0A), it indicates light intensity in this period is very strong and the smart strobes are not needed to function.

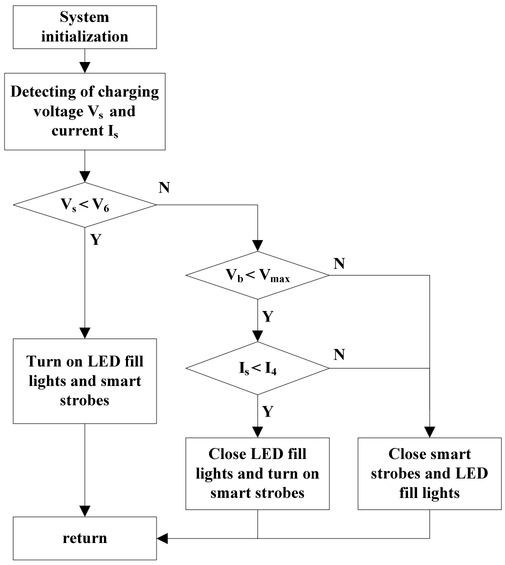

Figure 6. Flow of Flexible Light Supplementing

3) Adoption of sleep mode

In the system non-operating situations such as at night and no vehicles traveling on freeway, etc for FVMS, close the main equipments including snap cameras, network cameras, smart strobes and LED supplement lights; and ensure basic equipments such as microwave radar testers and optical transceivers online.

4) The first passing car capturing

When facing numerous vehicles passing the FVMS and the interval time between the adjacent two cars is very short in peak traffic, it only needs measure and record the information of the first car passing through the FVMS and whether the following vehicles exceed the limit will be able to judge. The next capturing action will be executed the moment the duration of the above situation reaches to the pre-set time t.

5. Analysis of the Actual Operating Data and Conclusions

Actual operating data of the PV system in the FVMS on Chongqing freeway are obtained by using the wireless data transmission equipment-DTU as the data sender and the local developed PC software as the data receiver. The following graphs are plotted according to the analysis of the gained data.

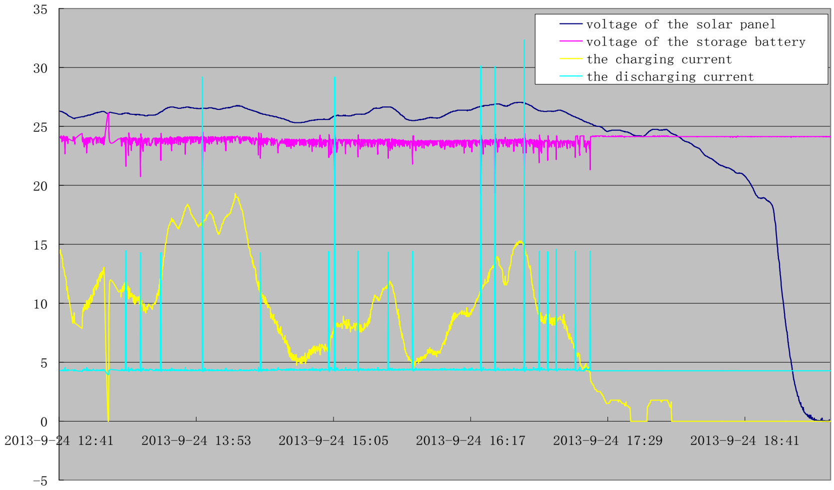

Figure 7. Charging and Discharging of the PV System 1

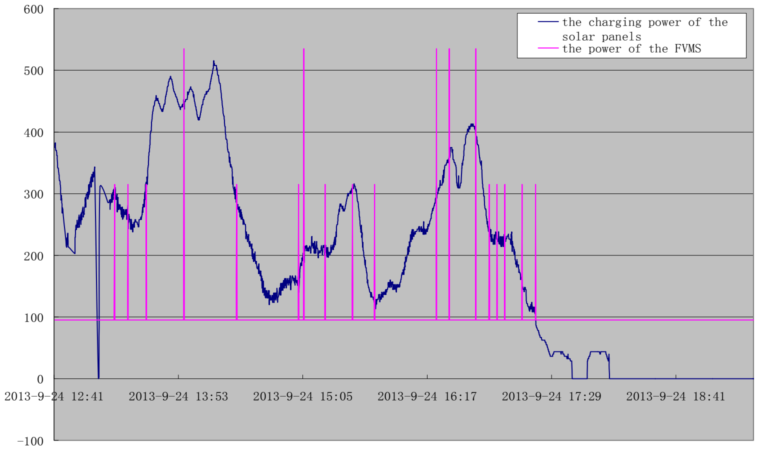

Figure 8. Charging and Discharging of the PV System 2

Components of the PV system in this FVMS are 8 polycrystalline silicon solar panels whose rated power is 196.5W, 6 maintenance-free lead-acid batteries whose capacity is 100AH and normal voltage 12V and 8 dedicated PV controllers. Every controller matches with one solar panel, all controllers connect with the battery pack, seven of them only control the charging process and the remaining one connected with solar panel, battery pack and the FVMS controls both charging and discharging process. Network cameras, panoramic cameras, velocity measuring radars and microwave radar testers should be in work during the system non-operating situations; then turn one group of snap camera and smart strobe on when there are vehicles passing through the FVMS in the single lane and turn two groups on while vehicles are passing in the double lane; LED supplement lights will be turned on at night. The analysis of graph 7 and 8 illustrates the specially designed PV system has higher photoelectric conversion efficiency and power utilization; the improved MPPT algorithm for PV panels and charge-discharge arithmetic for storage battery can be sufficiently realized in the controller. In addition, this FVMS has a strong stability and functions well in actual application.

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