硅型光伏电池的电特性及太阳能发电

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摘要：阐述硅型光伏电池的电特性，讨论等效电路图、伏安特性曲线和硅电池的光照特性，介绍阳光跟踪器结构，最后给出硅型光伏电池的应用实例。

关键词：硅型光伏电池；等效电路图；伏安特性曲线；光照特性曲线；阳光跟踪器

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太阳能电池是直接把光能转换为电能的半导体器件，其工作原理是：太阳光照在半导体 P-N 结上，形成新的空穴-电子对，在 P—N 结电场的作用下，空穴由 n 区流向 p 区，接通电路后就形成电流。由单品或多晶硅片半导体器件组成的太阳能电池，简称为硅型光伏电池。

太阳能发电有两种方式，一种是光—热—电转换方式，另一种是光—电直接转换方式，目前主要采用光—电直接转换方式。光—电直接转换方式是利用光电效应，将太阳辐射能直接转换成电能，光—电转换的基本装置就是太阳能电池。晶体硅太阳能电池是一种由于光生伏特效应而将太阳光能直接转化为电能的器件，是一个半导体光电二极管，当太阳光照到光电二极管上时，光电二极管就会把太阳的光能变成电能，产生电流。

以下讨论硅型光伏电池的电路特性。

1 硅型光伏电池的电路特性

硅型光伏电池的等效电路图如图 1 所示，由光生伏特效应而产生的电流（简称光生电流）I_{ph} 看作是一个恒流源与一只正向二极管并联，I_d 为流过二极管的正向电流，又称为暗电流。R_{sh} 为旁路电阻，是由光电池表面污浊和半导体晶体缺陷引起的漏电流所对应 P—N 结漏泄电阻和电阻边缘的漏泄电阻等组成，约几千欧姆；I_{sh} 称为漏泄电流。R_s 为与外电路负载电阻 R_v 串联的电阻，R_s 是由电池的体电阻、表面电阻、电极导体电阻、电极与硅表面间接触电阻和金属导体电阻等组成，约为 1Ω，R_{sh}、R_s 均为硅光电池本身固有电阻，相当于光伏电池的内阻，暗电流 I_d 可用下式表示[1]：

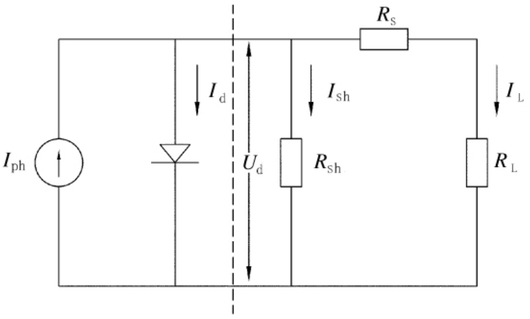

图 1 硅型光伏电池等效电路图

$$I_d = I_o\left(\exp\frac{qU_d}{nKT}-1\right) \tag{1}$$

式中：I_o 为光伏电流内部等效二极管的 P-N 结反向饱和电流；q 为基本电荷常数；n 为 PN 结二极管曲线因子，K 为玻尔兹曼常数；T 为硅光电池工作温度。

光生电流 I_{ph} 是光强和温度的函数，表示为：

$$I_{ph} = I_{Sco}\left(\frac{S}{1000}\right)+S_o(T-T_O) \tag{2}$$

式（2）中：S 太阳辐射照度（W/m²）；T_o 为标准测试下硅光电池温度；I_{SCo} 为标准测试下硅光电池短路电流；S_o 为温度影响系数。

从图 1 可看出，接入负载电阻 R_L 后电流 I_L 为：

$$I_L = I_{ph} - I_d - I_{sh} \tag{3}$$

$$U_d = I_L\cdot R_S + I_L\cdot R_L \tag{4}$$

$$U_d = I_{sh}\cdot R_{sh} \tag{5}$$

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将（1）、（5）式代入（3）式得：

$$I_v = I_{ph} - I_0\left(\exp\frac{qU_d}{nkT} - 1\right) - U_d / R_{sh} \tag{6}$$

以上（1）、（2）及（6）式可以得到受太阳辐射照度 S，硅光电池工作温度 T 和外负载电阻 R_L 影响的硅光电池的电压—电流关系曲线，简称为伏安（I–U）特性曲线，若选取输出电压 V 为横坐标 x 轴，输出电池 I 为竖坐标 y 轴，可以得到电压—电流特性曲线，如图2所示。描述硅光伏电池特性的参数主要包括以下部分[3]。

（1）开路电压 V_{OC}：硅光电池处于开路状态，$R_L \to \infty$ 时电池两极之间的电位差。

（2）短路电流 I_{SC}：硅光电池处于短路状态，$R_L \to 0$ 时测量的电流。

（3）最大输出功率 P_m：硅光电池 I—U 特性曲线上，电流与电压乘积的最大值。

（4）最佳工作电流 I_m 和最佳工作电压 U_m：硅光电池 I—U 特性曲线上最大功率所对应的电流和电压，如图2中M点（I_m、U_m）。

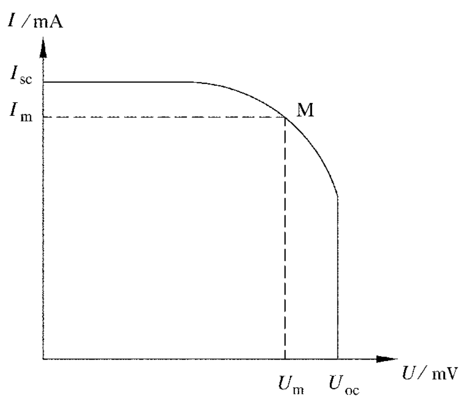

图2　硅光电池的 I–V 特性曲线

（5）转换效率 η：受光照硅光电池的最大输出功率 P_m 与入射到该硅光电池上的全部辐射功率 P_{sr} 的比，即：

$$\eta = P_m / P_{sr} \tag{7}$$

（6）填充因子 FF：受光照硅光电池的最大输出功率 P_m 与该电池的开路电压 U_{oc} 和短路电流 I_{sc} 乘积之比，即：

$$FF = P_m / V_{oc} \cdot I_{sc} \tag{8}$$

硅光伏电池的特性参数通常都是在AM1.5太阳光谱，温度为25℃，光源辐射照度为1000W/m^2 的标准测试条件下得到的，其特性曲线受温度和入射光谱、辐射照度影响很大，例如（1）式中硅光电池内部等效二极管反向饱和电池，可用下式计算：

$$I_o = AT^3 \exp\left(-qE_{go} / KT\right) \tag{9}$$

式（9）中：A 为常数；E_{go} 为绝对零度下外插禁带宽度。

硅光伏电池的工作温度，可由下式计算：

$$T = T_a + T_c \cdot S \tag{10}$$

式（10）中：T_a 为环境温度；T_c 为硅光电池的温度系数；S 为太阳辐射照度。

硅光伏电池的温度特性，可参看文献［2］的讨论，开路电压 V_{oc} 随温度升高而下降，短路电流 I_{sc} 随温度升高而上升，但电池的转换效率 η 随温度升高而下降，温度每升高1℃，硅光电池电池转换效率下降0.35%~0.45%，由此推算，在25℃工作的硅型光伏电池的转换效率比70℃工作时高出20%以上。

2 硅型光伏电池的光照特性与阳光跟踪器

硅光伏电池的光照特性受太阳光的入射光谱，辐射照度影响很大，图3列出硅光电池短路电流 I_{sc}、开路电压 V_{oc} 和输出功率 P_m 与入射光照度（辐射照度）之间的变化曲线，其中短路电流 I_{sc} 随光强而线性增加；开路电压 V_{oc} 在弱之时随光强增加很快，但在强光时趋于饱和，最佳输出功率 P_m 随光强而直线上升。

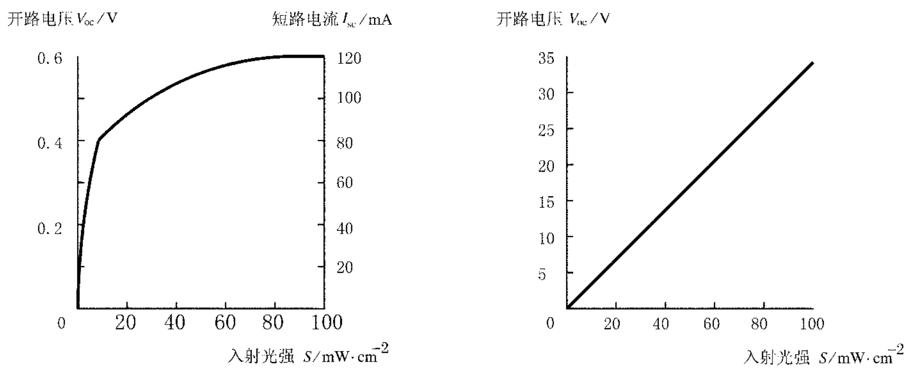

图3　硅光电池短路电流 I_{sc}、开路电压 V_{oc} 和最佳输出功率 P_m 与入射光强的关系曲线

文献［3］讨论阳光跟踪器工作原理及设计要点，为了提高硅型光伏电池板的转换效率[4]，拟采用一种带阳光跟踪器的可跟踪太阳方向转动的硅型光伏电池板[5]。该系统由操作平台、硅太阳能电池板、电动推杆、转动合页以及阳光跟踪器等组成。如图4所示。

太阳能电池板与操作平台采用两个特制的不锈钢合页连接，电池板背面为铝衬板，在铝衬板用铝合金拉钉固定一个铝制连接耳板，此耳板通过一个不锈钢销轴与操作平台上的支座耳板连接并可转动。太阳能电池板上端可设置两个阳光跟踪器，控制两个方向的转动，但通常只使用一个，另一方向微动部分用手控系

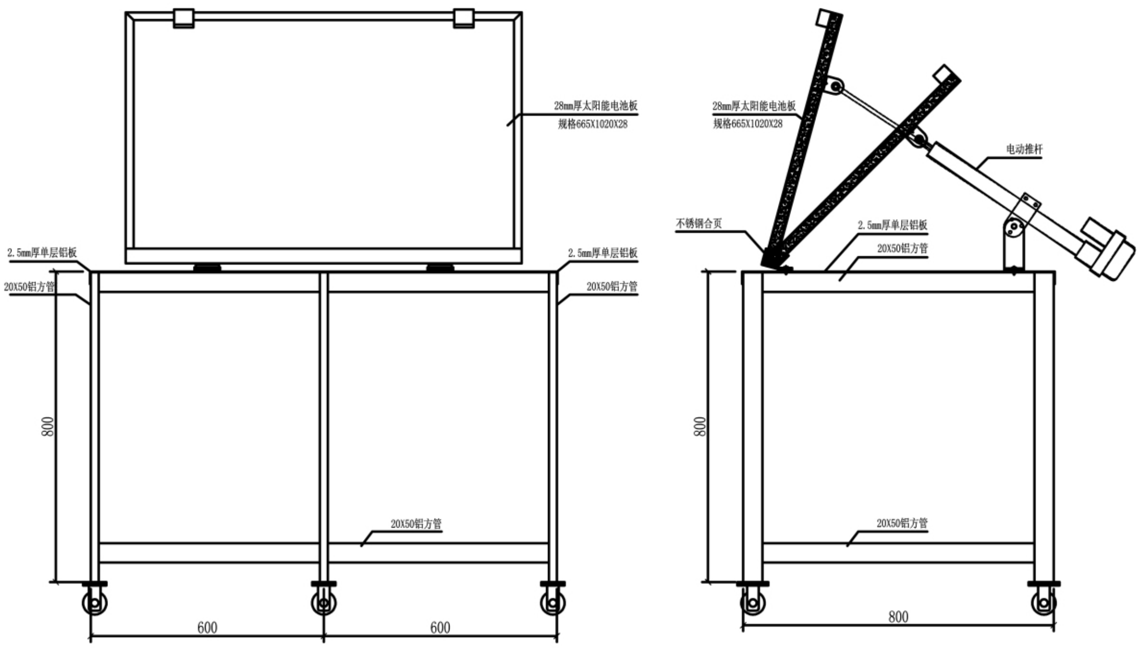

图 4　由阳光跟踪器控制的硅光电池板

统设定即可，阳光跟踪器通过信号控制系统控制电动推杆来实现太阳能电池板随太阳的方向而上下转动，左右转动采用手控系统控制。从而得到最佳的输出功率。

3 应用及举例

实际光伏太阳能发电系统可根据实际需要，将若干硅型光伏电池组件经串、并联，排列组成光伏阵列，满足光伏系统实际电压和电流的需要。硅型光伏电池组件串联，要求所串联组件有相同的电流容量，串联后的阵列输出电压为硅型光伏电池输出电压之和，相同电流容量硅型光伏电池串联后其阵列输出电流不变；硅型光伏电池组件并联，要求所并联的所有光伏电池输出电流之和，而电压保持不变。一般说来，常用的晶体硅型光伏电池组件或模块内部标准串联数量是 36 个或 40 个，1 个硅型光伏电池额定输出电压大约 0.45V，组件额定电压大约是 16~18V，正好可以为额定 12V 的蓄电池进行有效的充电[6]。

光伏太阳能发电系统容量计算如下。

（1）光伏电池容量计算：进风口面积为 1100mm×660mm，根据不同厂家的不同性能，选用多晶硅，对应功率在 50~100W 之间。考虑到蓄电池的额定电压一般为 12V，所以可请厂家设计 1100mm×660mm，17V，80W 左右的多晶硅电池板。

（2）蓄电池容量计算：一般选用固定型密封式铅酸蓄电池。通常最大放电深度可达 0.8，为了延长蓄电池使用寿命，设计最大放电深度为 0.7。80W 光伏电池，一般选择 200Ah 的蓄电池足够了。

（3）负载容量：选择 12V 带齿轮组的减速电机，额定功率 16W，最大扭矩 37kg·cm。单片机控制板功率不超过 9W。考虑到电机在 12 小时工作时间内，大部分时间处于停止运行状态，蓄电池及光伏电池容量足够支持系统运行。

4 实例

本项目研制的硅型光伏太阳能发电系统，已应用于节能型热通道光伏幕墙的通风装置和遮阳百叶的传动装置。前者在热通道光伏幕墙的进风口，安装一台 20W 风机，由太阳能发电蓄电池提供电功率，驱动风机运转，向热通道送风，降低热通道温度，由于热通道内安装有硅型光伏电池，因而降低了其工作环境温度，同时降低了室内温度，改善人居环境。后者提供遮阳百叶传动电机功率约 12W，通过智能控制系统在强太阳光时遮阳百叶闭合，降低室内温度，收到良好的效果。

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factors carburetor starting to find the best improve the program. The results show that the improved engine torque increased on average 46.9%, average power increased 46.5%; lower average fuel consumption rate of 31.3%.
Key words: XB1P60F gasoline engine; performance; improvement; study

10-08-73 Research on Energy-Saving Technology of Plastics Injection Molding Machine Driven by Servo Motor-Driven Hydraulic Pump

ZHANG Tao, LI Bin-li, LI Zi-yu(Guangdong Yizumi Precision Machinery Co., Ltd, Shunde528306, China)
Abstract: A new driving and controlling technology of plastics injection molding machine with servo motor-driven hydraulic pump, as for the driving and controlling system, permanent magnet synchronous motor (PMSM) is used for the driving of hydraulic pump., it makes great improvements in energy-saving performance, fast dynamic response, stable pressure control and better low speed performance. After experiment and application, it is concluded that the new driving and controlling technology realizes better energy-saving performance and higher controlling precision.
Key words: plastics injection molding machine; energy-saving technology; servomotor-driven hydraulic pump

10-08-76 The Analysis for Elevator's Green Based on Multilevel Analysis and Weight Average Method

TANG Dian-bo(Hitachi Elevator (China) Co., Ltd, Guangzhou511430, China)
Abstract: In order to produce and apply green elevator, it is necessary to know the degree of elevator's green, so there must be a set of objective standard and scientific method to measure them. This paper builds an appraisement mode that is from top to bottom and it include the three key factors of elevator green. Then it is able to calculate the score of elevator's green with multilevel analysis method and linearity weight method based on the mode. At the end of this article gives a practice example,it offers references for correlative people.
Key words: elevator; green; multilevel analysis; weight average

10-08-79 MPPT Analog Controlling Circuitry of Small Power Photovoltaic System

LIU Zheng-qi, LI Ji-dong(Bengbu Naval Petty Officer Academy, Bengbu233012, China)
Abstract: Owing to the limitation of installation condition, high-power solar cell can't be used in some special sites, but the application of maximum power point tracking (MPPT) can, in certain conditions, strengthen their output capability. Conventional MPPT isn't applicable to small power solar system, so we considering the distribution disciplinarian of solar cell's power point as well as high efficiency technology on switching power supply, put forward a simple and convenient way of maximum power point tracking, in which analog circuitry instead of single chip microcomputer (SCM) is applied.
Key words: solar cell; maximum power point tracking; analog circuitry; DC/DC converter

10-08-82 Silicon-Based Photovoltaic Cells Circuit Characteristics and Solar Power Applications

LONG Zhi-jun[1], WANG Qiu[1], XIE Guan-jian[1], CHEN Hai[2], GUO Jin-ji[2], YANG Huan-jun[1](1.Zhongshan Shengxing Co., Ltd, Zhongshan528412, China; 2. Department of Applied Mechanics and Engineering, Sun Yat-sen University, Guangzhou510275, China)
Abstract: The silicon-based photovoltaic cell electrical characteristics were described. The equivalent circuit, voltage characteristics of the light curve and the characteristics of silicon cells were discussed. The sun tracker was proposed. And the structure of silicon-based photovoltaic cells was designed. Finally, application examples were introduced.
Key words: silicon-based photovoltaic cells; equivalent circuit; V characteristics; light curve; sun tracker

10-08-85 HIL Test Bed Based on Anti-Directional Bi-Rotary Motor

ZHANG Yin-xian(Guangzhou Automotive Group Co., Ltd. Automotive Engineering Institute, Guangzhou510640, China)
Abstract: Aim at a new type anti-directional Bi-rotary (ADBR) motor used for automotive, a HIL of ADBR motor test is set up on the powertrain test-bed and design the interface module for the key node. This test-bed can be used to supervise and debugs correlative parameters. The result of the experimentation validates the rationality of test-bed.
Key words: test-bed; anti-directional bi-rotary motor; hardware-in-the-loop

10-08-89 A Solution to Anti-Interference of Vehicle-Braking Detection

CHEN Tao(Guangzhou Baiyun Industrial& Commercial Senior Technical School, Guangdong Guangzhou510450, China)
Abstract: The paper analyzed the impact of vehicle braking Detect results of the interference factors, and proposes a solution through software filtering measures.
Key words: vehicle-Brake Detection; interference; software filtering

10-08-92 Design of Infrared Remote-Control Downtiming Answering Racer with Multi-Lines Based on Single Chip Microcomputer

LU Fei-yue(Guangzhou Panyu Polytechnic, Guangzhou 511483, China)
Abstract: This paper introduces a downtiming answering racer with Multi-lines based on principle of infrared remote-control answering input and AT89S52 Single Chip Microcomputer. Its system composition and design of software and hardware are presented. The result after debugging and running shows that the system can achieve Timing Quick Answer and is simple and intuitionistic and quick and has high application worth.
Key words: single chip microcomputer; infrared remote-control; timing quick answer; design

10-08-95 Design and Application of High-Rise Building Outward Inclined Cell Wall Lifting Equipment

MA Xiang-li, WANG Wen-huan, LIN Ling-gan, WU Hai-feng, ZHONG Dong-chang(Zhongshan Shengxing Co., Ltd, Zhongshan528412, China)
Abstract: The outward inclined cell wall lifting equipment of high-rise building and curved shape of the curve silicon-based photovoltaic cell electrical characteristics were introduced. According to static equilibrium and method to find the location of centroid, lifting load capacity was calculated, and the curved track for the engineering crane travel was designed. Finally, application examples were introduced.
Key words: outward inclined wall; lifting; centroid; carrying capacity

10-08-97 Data Recording Module Design Based on CAN Bus

WEI Jian-jun(Guangzhou Automotive Group Co.,Ltd Automotive Engineering Institute, Guangzhou510640, China)
Abstract: Most of vehicle electrical design are based on CAN Bus today, if we can make a flexible data recording module based on CAN Bus, using the sufficient data platform, it could be benefit to vehicle calibration and function test.
Key words: Data recording module; CAN Bus; LPC2136

10-08-100 The Network Teaching System of Automation Equipment Based on CC-Link

PAN Feng(Automation Technology Institute, Shenzhen Polytechnic, Shenzhen518055, China)
Abstract: Based on CC-Link fieldbus technology and the communication function of PLC and touch screen, with combination of the designed automation network teaching system, to discuss the CC-Link fieldbus technology hardware structure and software realization method, will focus on the detailed state of the communication between the equipments .
Key words: CC-Link; PLC; touch screen; network teaching system

10-08-102 Design of Video Surveillance System for the Hospital of SCUT

HE Feng[1], TIAN Xiang[2](1.Automation Engineering R&M Center, Guangdong Academy of Sciences, Guangzhou510070, China; 2.South China