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Design and Implementation of A Solar Array Simulator

Shivam Sachan[1], Mr. Brijesh Kumar Dubey[2], Mr. Amit Sharma[3]
[1]*Department of Electrical and Electronics Engineering PSIT, Kanpur, Uttar Pradesh*
[2, 3]*Assistant Professor Department of Electrical and Electronics Engineering PSIT, Kanpur*

Abstract: In order to test the performance and reliability of solar power system of satellites ,solar array simulator on earth is needed. Based on the solar cell's mathematic model, this paper designs a practical solar array simulator which can generate the solar cell's I-V character. Since the implemented solar array simulator has the same structure and power as the real system, it can simulate the actual operating of a real solar array to most extent Experimental results demonstrate the validity of this design which enables the further research on and diagnosis of solar power system.

I. INTRODUCTION

Solar energy is a kind of renewable energy widely used in residential photo voltaic system, transportation, as well as in aerospace industry. In the present space power domain, most of the satellite power systems use solar cells as their power core. The performance of the satellite power system directly affects the satellite's performance and working life. So, in order to improve the performance and reliability of the satellite power system, real time simulation and testing is of great significance. Solar array in space works in very critical conditions, sunlight and temperature change rapidly. The I-V characteristic of every solar cell varies with illumination and temperature. Therefore it is necessary to simulate the solar array's working conditions in space by using a solar array simulator (Solar Array Simulator, SAS). SAS's main task is to supply power for various subsystems on the satellite while permitting the testing of the actual solar array of satellite on ground.

II. THE MATHEMATICAL MODEL OF SOLAR CELLS

The equivalent circuit generally used for the photovoltaic solar cell is shown in Fig. 1. This circuit consists of a current source, a diode, a series resistance and a parallel resistance.

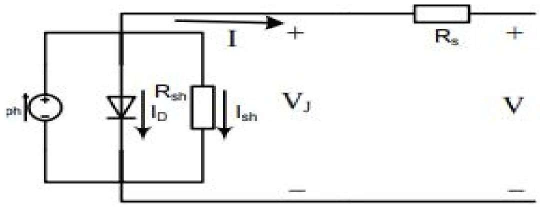

Fig. 1. The equivalent circuit of the solar cell

According to general diode model, the diode current can be described as

$$I_D = I_0\left[\exp\left(\frac{eV_J}{nKT}\right)-1\right] = I_0\left\{\exp\left[\frac{e(V+IR_s)}{nKT}\right]-1\right\} \quad (1)$$

Where I0 is the diode saturation current, VJ is the junction voltage, e is the charge of electron, n is diode quality factor dependent on the recombination processes in the junction, usually from the interval between 1 and 2, k is Boltzmann's constant and T is temperature. Then the I-V character of solar cells is

$$I = I_{ph} - I_D - I_{sh} = I_{ph} - I_0\left\{\exp\left[\frac{q(V+IR_s)}{AKT}\right]-1\right\} - \frac{(V+IR_s)}{R_{sh}} \quad (2)$$

Where IPH is light generated current, I is output current, V is output voltage, RS is series resistance, Rosh is parallel .

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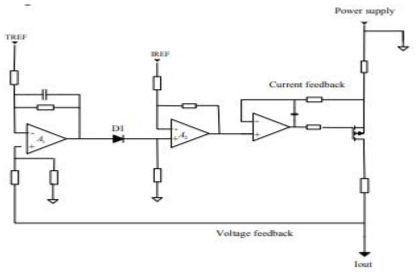
III. HARDWARE DESIGN

According to the mathematical model and equivalent circuit, the output I-V curve of the solar cell is an exponent curve. It can be simulated with a current source simulated with the circuit shown in Fig. 2.



This circuit has two feedback loops: one current feedback Loop and a voltage response loop. In the current reaction loop, IREF short circuit is a current reference, corresponds to Light intensity and 0 to 100% can be adjusted. In the voltage feedback loop, TREF is the open circuit voltage Reference which corresponds to ambient temperature Solar Cell When the reaction voltage is below TREF, then

The output of the amplifier A1 is negative and the diode D1 is closed. Again The output of A2 is determined by the IREF and the output current

There is a continuous short circuit current. When the response voltage Increases, the output of A1 becomes positive and diode D1 is turned on.

The output of A2 is determined by the current of D1, it increases with it Output voltage grows. The output voltage increases According to the I-V of the diode, the output current decreases Specialty. To simulate the actual satellite power system, a solar Array simulator is built with 30 similar string modules.

The block diagram is shown in Fig. 3.

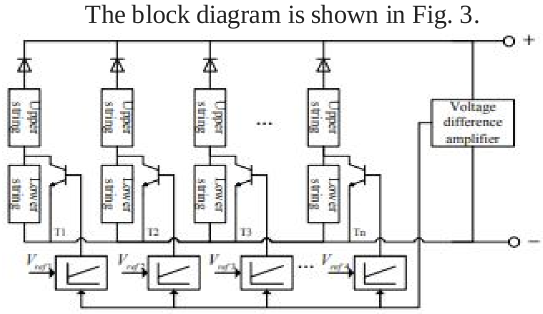


Fig. 3. The block diagram of solar array simulator

Each string module consists of two parts: upper string and Low string, they have the same I-V feature and are The series is connected in. All the center faucets are connected to a shunt Regulatory in which there is equal amount of branches with SAS. The shunt regulator is used to regulate DC bus voltage and make it Stable at the expected level. Shunt regulator locates bus It compares with voltage and reference voltage Each The branch consists of a PI regulator and a transistor, which shines Redundant flow of solar string module Schematic of Shunt Regulator Branch is given in Figure 4

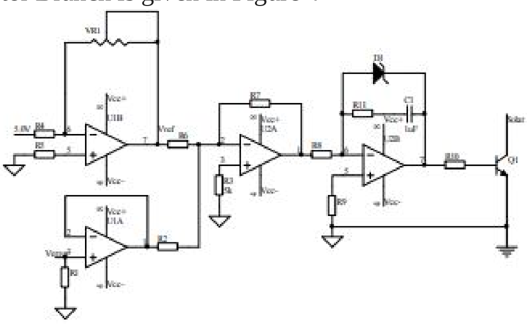


Fig. 4. a shunt regulator branch schematic

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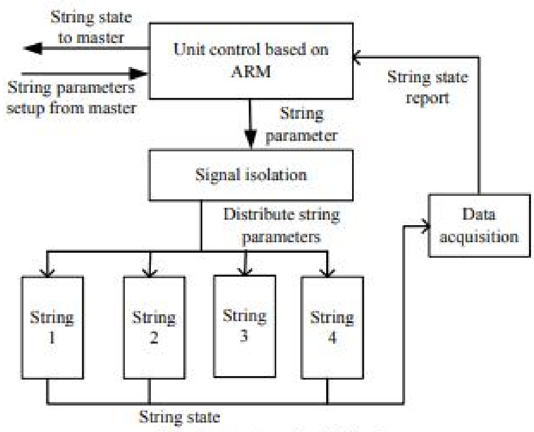
In this circuit, the difference between the VERR Actual DC bus is Voltage and reference voltage Reference voltage of ref By adjusting the variable, each branch is gradually increased Resistance VR1. Amplifier A1 and A2 have a PI regulator, And the modulated center of the transistor Q1 is connected to the tap. When error is smaller than ref, PI closes the regulator And this regulatory branch does not work; When Error is big Then it works and starts separating the present.

IV. CONTROL SYSTEM

SAS consists of 30 string modules, but an industrial
Standard chassis can hold only 4 string modules. So 4 modules And their re-controlled control circuit are mounted in a standard Chassis and SAS include 8 such units. Are in as unit A unit control circuit, a signal isolation circuit and a data Acquisition circuit. Unit control circuit based on a high speed ARM 7 processors are primarily used for transferring and converting data.

AT91SAM7S is a member of Atmel's following Pin-Count Flash-microcontroller based on 32-bit RISC Processor It has 64k byte high-speed flash and 16k bytes SRAM consists of two universals in a large set of peripherals Synchronous asynchronous receiver transceiver (USART), a Serial Peripheral Interface (SPI) and so on. USART makes it Convenient to be connected to PC's serial port and SPI It's easy to run serial AD and DA chip With high speed ARM7, the unit receives the control circuit Command commands from the digital control serial port and decode it Quickly, then converts them to analog signals by DA. In The signals are separated by the signal isolation circuit and then given For each string module. String module output as output Voltage, current and temperature are also transferred to the unit Control circuit by data acquisition circuit. Fig. 5 is structure A SAS is controlled by an industrial PC. to control 8 SAS unit, a master control board has been developed by serial port To extend the serial port. Master control board is also based on one ARM has two serial ports, connected to a port The computer is connected with the other 8 units which one is made Master-client structure. It transfers control command to 8 units And gets unit states by polling mode. SAS block diagram is As shown in Figure 6.



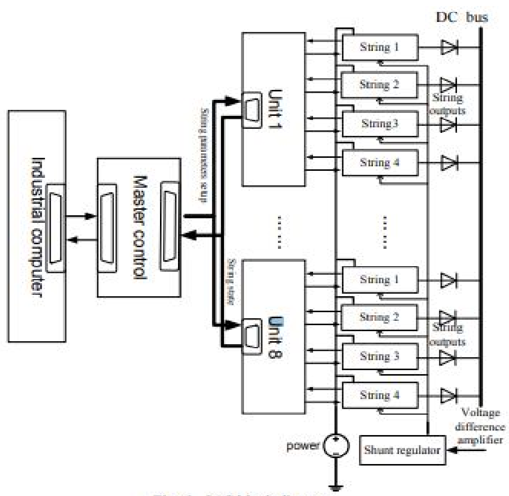


Fig. 6. SAS block diagram

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V. SIMULATION AND EXPERIMENT RESULTS

A. Simulation

To verify the pre-designed solar string module,

A PSPICE model is designed to emulate the I-V curve.

Simulation results are shown in Fig. 7 and Fig. 8. As shown Figure 7, the short circuit varies with the intensity of the current Illumination ask When are kept unchanged and E.C. Increased, the I-V curve moves vertically upwards. In Fig. 8, open Circuit voltage varies with temperature. When you keep sc unchanged and Voc increased, I-V curve shifted to the right Horizontal These curves correspond to the I-V specialty Given in (2)

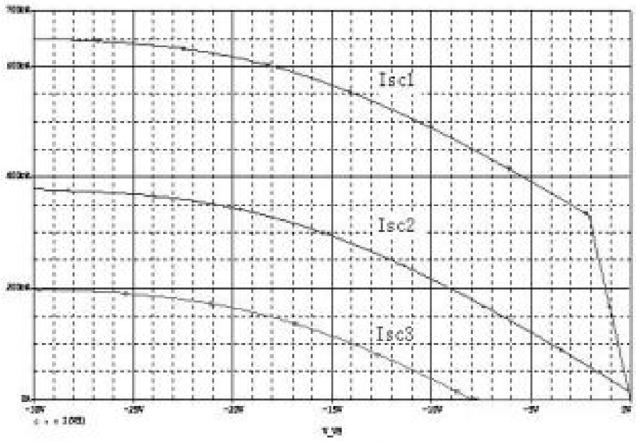


Fig. 7. simulated I-V curves with different illumination

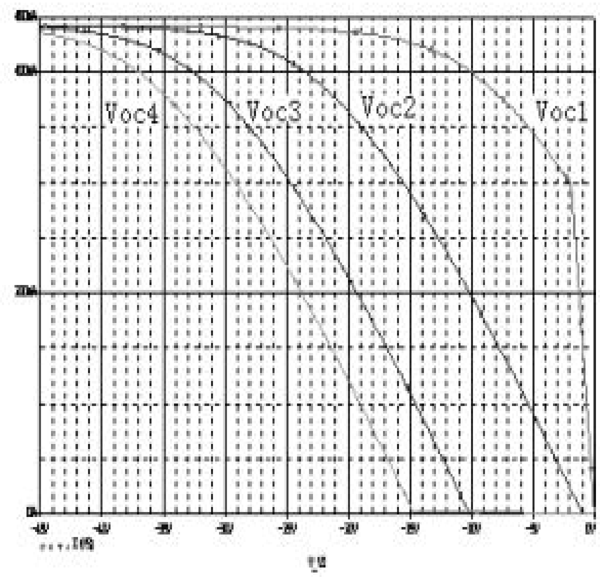


Fig. 8. simulated I-V curves with different temperature

B. Experiments

On the basis of design and simulation, a 2kw SAS has been built. To Examine the performance of each solar string and the I-V attribute, Sever experimental data has been taken to pull different I-V Curves The results are shown in 9 and Fig. 10. in The same Voc and sc with experiments, solar strings Simulations, and I-V curves are very close to simulations

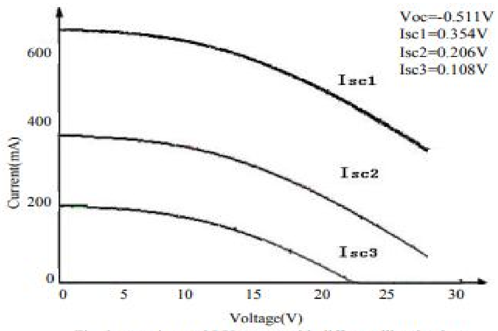
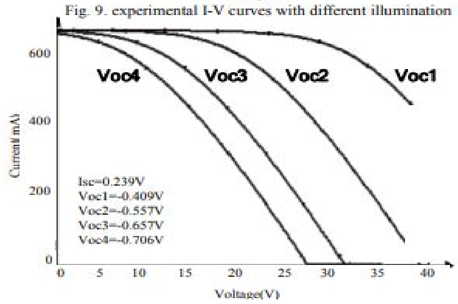


Fig. 9. experimental I-V curves with different illumination



C. Comparison

To verify the stability of SAS output Specialty with the actual solar array, it is necessary to test I-V curve of a string of SAS and compare it with The actual data of the solar cell. Fig.11 shows experimental result.

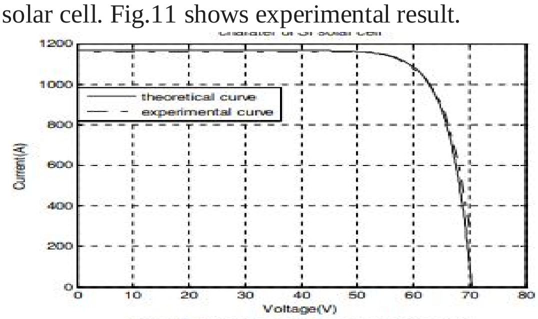


Fig. 11. Experimental-theoretical I-V curves

In this experiment, the short circuit current is set to 1.16A and Open circuit voltage is set at 70V. Theoretical curve Using solar cells, calculated with the actual solar cells parameter mathematical model. It can be seen that the SAS's I-V curve Completely matches the actual solar array. It proves that the S.A.S. Performs well in emulating the actual solar array.

VI. CONCLUSIONS

Based on a practical solar array simulator has been introduced Mathematical model of solar cell. Experiments prove that The I-V feature of SAS is similar to the actual solar Array, so it can simulate complex operation status The actual solar array in space. Since the simulator has the same output Power and array architecture for the actual solar array, it can be The actual satellite is used to emulate the power system. In the future, this The simulator can be used as an experimental platform and Connected to other subsystems of the satellite, which gives support Ground testing of other sub-systems.

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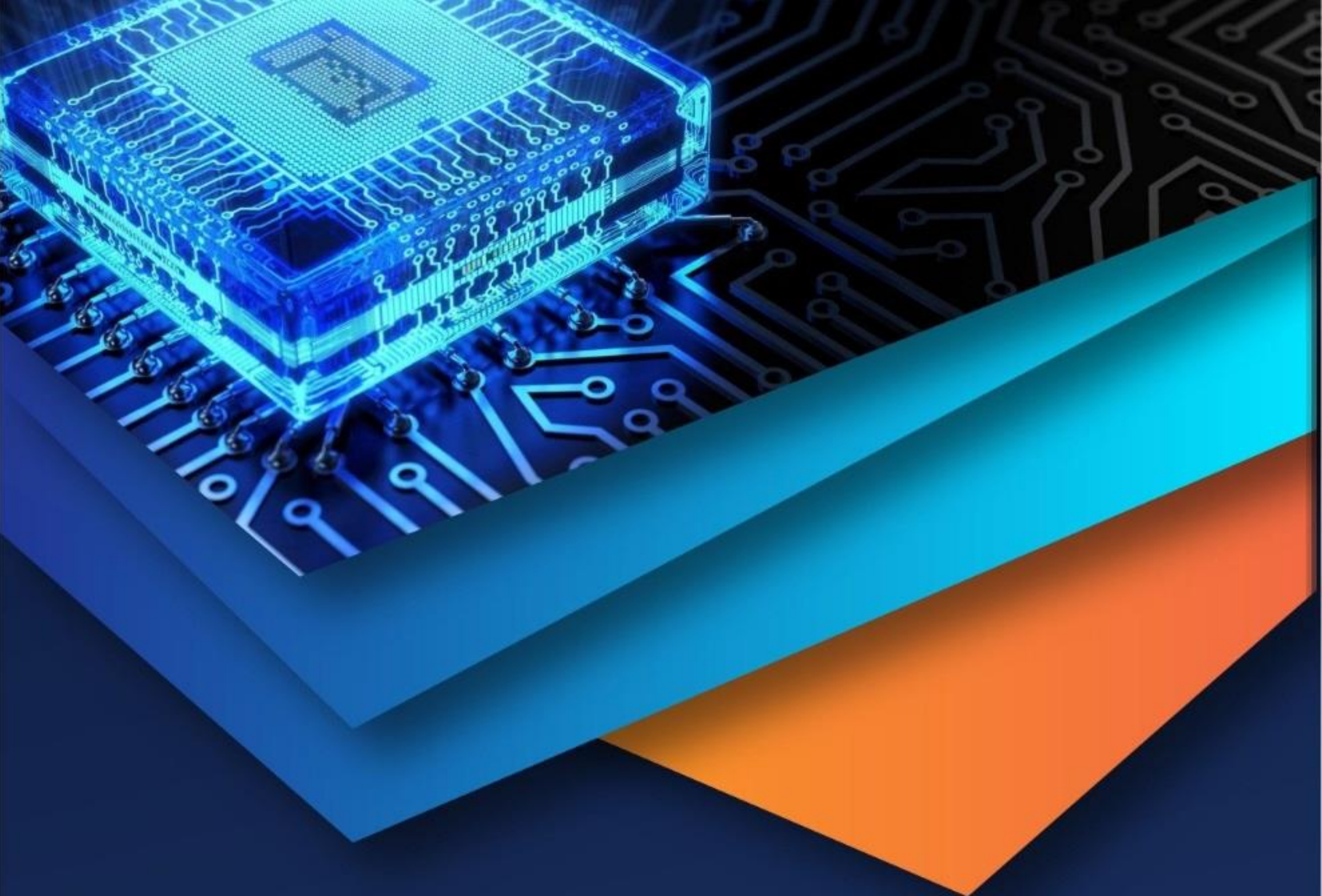

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