# An Efficient Power Management Approach for Self-Cleaning Solar Panels with Integrated Electrodynamic Screens

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*Abstract---* **Electrodynamic screens (EDS) have proved to be an efficient method for dust removal from a variety of surfaces including photovoltaic (PV) cells. An EDS is composed of a series of parallel electrodes on a substrate that is energized by a three phase high-voltage amplifier. This technology would be critical for deployment of PV arrays in remote, dusty atmospheres such as the surface of mars. As dust collects on PV cells, the amount of light hitting the surface is decreased, thus decreasing the overall power output. It is not feasible to use moving parts in high-dust areas due to the damaging effects dust has on joints, as replacing these joints is often impossible in the many remote regions where PV arrays are deployed. EDS are an ideal dust mitigation technology for these conditions, as it has no moving parts. A downfall of an EDS is that it requires a high-voltage external power source for its operation, but the EDS can be made self-sustainable with the power output from the PV cell itself. Our goal is to develop an experimental system that incorporates a transparent EDS with a PV array as its power source, allowing us to study the total efficiency of a PV power system with an EDS for dust removal.**

## I. INTRODUCTION

Dust poses a serious impediment to the success and operation of the Mars Rovers and other remote, solar powered devices. The success of these devices depends on their solar panels ability to produce energy effectively. The high concentration of airborne dust particles and the large number of dust storms make dust removal a critical component for future devices. Electrodynamic screens (EDS) [1,2] are a viable dust mitigation system, but require a high voltage external power supply. An integrated EDS-PV array system to measure the effectiveness of dust removal and solar power conversion is detailed here. The block diagram of the system is as shown in *Fig. 1*. The integrated system includes a transparent, three-phase EDS that lies upon a solar panel. Power to the EDS is regulated with a MOSFET switch bank that is controlled by a Texas Instruments Digital Signal Controller (DSC). The unregulated output from the solar panel enters a power control module controlled by the DSC for maximum power output. The power output enters a power manager that splits the power into several DC supplies to feed the DSC, MOSFET switch bank, and any onboard battery. The information presented here explains the operation of each functional module in detail.

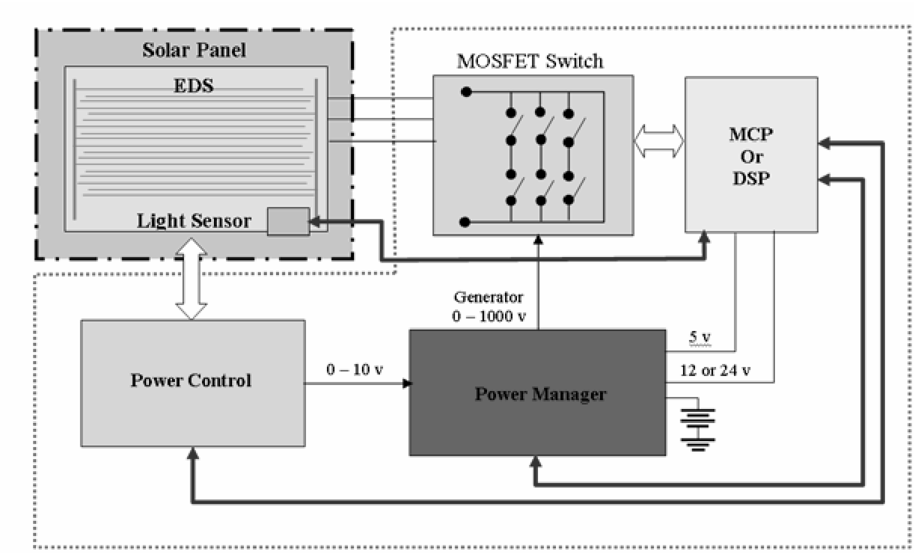


Fig. 1 Block Diagram of EDS/PV Array System

## II. INTEGRATED PV ARRAY-EDS SYSTEM

### *A. Electrodynamic Screen*

The electrodynamic screen (EDS) consists of a series of alternating electrodes suspended in a transparent substrate, illustrated in *Fig. 2*. The electrodes are powered by a three-phase ac drive signal supplied by the MOSFET switch bank.

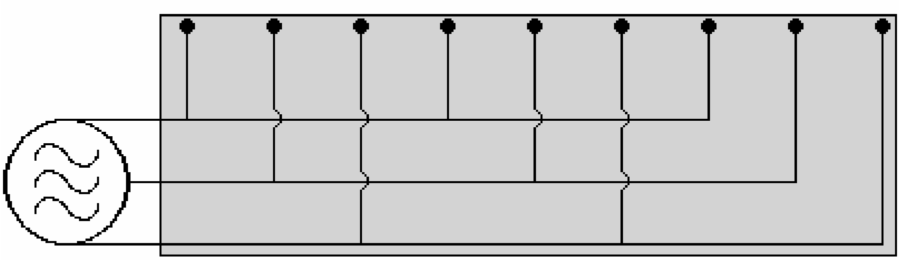

Fig. 2 Three-phase Electrode Curtain [3]

The three-phase high-voltages create a traveling wave [4] with a strong translational energy that can move the triboelectrically charged dust particles from one end of the substrate to another. Uncharged particles that may become deposited on the screen soon become charged by polarization of a charge or through induction, allowing it to also be cleared from the surface. Although a single or dual phase screen is easier to produce, experiments have shown a three-phase screen to be far more effective at dust removal.

### *B. MOSFET switch bank*

The MOSFET switch bank consists of three half-bridge MOSFET's that together form a three-phase bridge, as seen in *Fig. 3*. . The MOSFET switch bank converts a high DC voltage to three-phase AC voltages. The high DC voltage (1000 V) is generated from 12 V by a step-up DC-DC converter. The MOSFET switch bank and high voltage generation are depicted in *Fig. 3*.

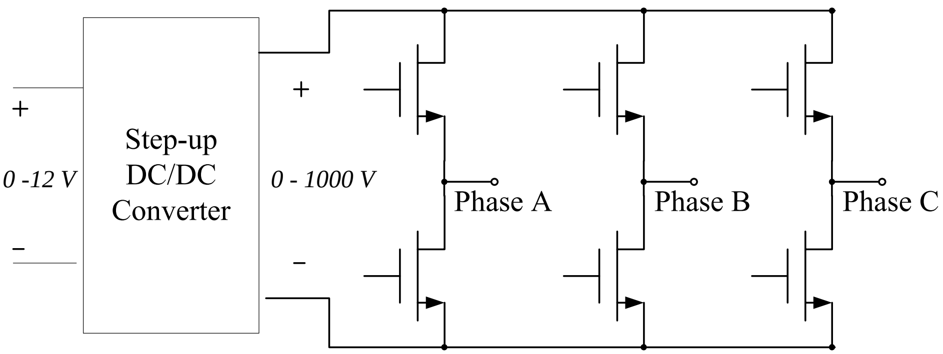


Fig. 3 Three-phase Bridge

The digital signal controller controls which transistors are on, creating three square waveforms, each shifted 120° of another. The three square waveforms are illustrated in *Fig. 4*.

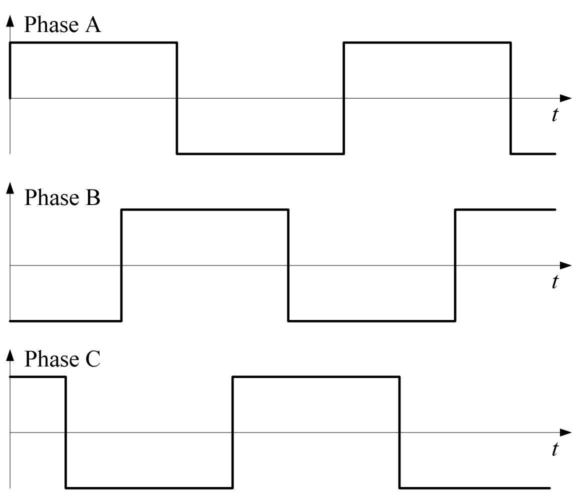


Fig. 4 Three-phase Square Waveforms

### *C. Power control*

A common problem with solar cells is that the current and voltage output from the cell often do not result in the highest possible power output, because output power is dependent on light intensity, temperature, and load characteristics. A relationship exists between current and voltage at constant temperature and light intensity such that as current increases to a certain point, the voltage is drastically decreased (*Fig. 5*). This point results in the highest possible power and is known as the max power point (MPP).

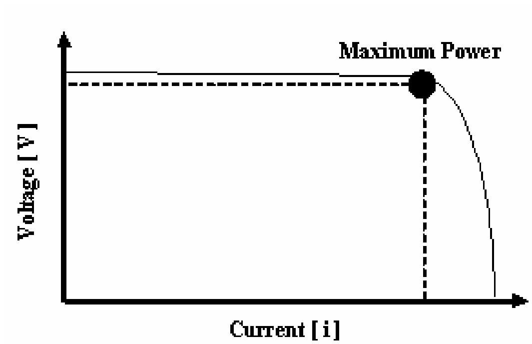


Fig. 5 Voltage-Current Curve

MPP tracking requires a power converter between the PV array and the load. One way of controlling the MPP is by regulating the impedance in the power converter to match the output impedance of the PV array.

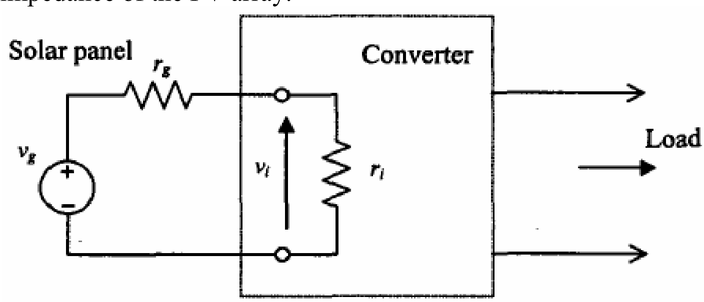


Fig. 6 Solar Panel with DC-DC Converter

The circuit of the power converter shown in *Fig. 7* is studied in [5]. In our experimental system the circuit is used and controlled with the digital signal controller. One PWM output of the digital signal controller is used to control MOSFET *S* of the power converter in Fig. 7. The input impedance of the power converter depends on the duty-cycle of the PWM signal. Hence, the digital signal controller realizes the MPP tracking by setting the duty-cycle of the PWM signal properly.

The power converter's active component is a DC-DC Converter and is used in conjunction with the digital signal controller (DSC) to regulate the output from the solar panel to result in the maximum power output. The DC-DC controller uses two large inductors and a power MOSFET to control the input impedance of the DC-DC converter.

The controller uses the inductors to temporarily store power from the cell and the MOSFET to vary the input impedance. This circuit requires a Pulse-Width Modulation (PWM) signal generated by the DSC. While the PWM signal is low the MOSFET is open to ground, and the current through inductors increases. While the PWM signal is high, the MOSFET closed and the power stored in the inductors is sent to the load. The load used in this scenario is an 87Ω resistor. This resistor is used in place of a battery to eliminate risks of over-charging and variations in load resistance [5]. The power converted by the DC-DC converter feeds into the power management module.

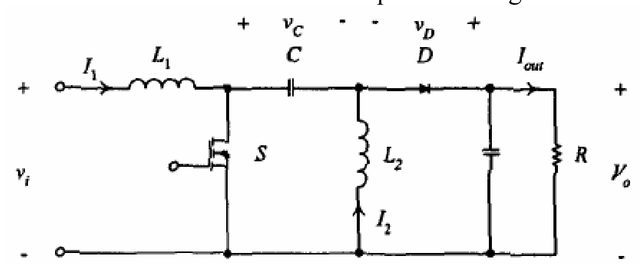


Fig. 7 Power Converter Circuit

### *D. Power management*

The purpose of the power manager is to split and convert the power produced from the solar panel to the necessary devices. The power manager provides the necessary DC supply to the Digital Signal Controller, step-up DC-DC converter for MOSFET switch bank, various electronic circuitry within the system, and any on-board battery system. The power manager is essentially many DC-DC converters within one module.

### *E. Digital signal controller*

A Texas Instruments digital signal controller (DSC), model TMS320F2812, is used to realize all control and detection functions within the experimental system. The DSC and developed electronics are shown in *Fig. 8*, including the DSC, MOSFET switch bank, power control module, and power manager.

Fig. 8 Digital Signal Controller and Complementary Circuitry

The power control program developed uses an Analog-Digital Converter (ADC) to measure the input voltage and current, the output voltage and current, and calculates the power produced by the solar panel. In the program a perturb-and-observe (PAO) method is used. In this algorithm, the program measures and averages one hundred samples of the output voltage and output current, then increments the PWM duty cycle. The DSC measures and averages one hundred more samples after the PWM is incremented. If the change in power is positive, the PWM duty cycle is incremented once again [5]. If the change in power is less, the program begins to decrement the duty cycle. This process continues with the program increasing or decreasing the duty cycle until an optimum power conversion is reached, and is known as the perturb-and-observe method.

To measure the power produced by the solar panel and the efficiencies of the control program and DC-DC converter, the DSC's Serial Communication Interface (SCI) was employed to communicate with a client Windows workstation. The DSC transmits the voltage and current values directly from the solar panel, as well as the converted voltage and current values. A .NET program receives the data on the workstation and calculates the efficiency of the converter and displays the four received data values, calculated input and output power, and the efficiency of the control program. The DSC was shown to generate nominal efficiencies of 85% with a deviance of ±5%.

## III. CONCLUSION

The integrated electrodynamic screen-photovoltaic cell system can be made efficient and without the use of an external power supply. Using the photovoltaic cell array for its power source, the EDS system has shown to effectively remove dust obstructing any light incident on the array, thus insuring power production is maximized.

Further improvements of the experimental system include using a low-power microcontroller (μC) to replace the digital signal controller and the development of high-efficient DC-DC converters in the system, which may result in higher total efficiency of the system.

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