Design and Development of Photovoltaic Systems

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Abstract

Crystal-Si, thin-film and multiple-junction solar cells are studied for solar energy harvesting, storage and management systems. Crystal-Si and thin-film solar cells are cost-effective and ensure efficiency ~20% and 15%, respectively. We examine affordable and practical solar cell solutions which though may not provide very high efficiency, but, ensure the desired electrical and mechanical characteristics, capabilities and features. In thin-film solar cells, the active semiconductor layers are polycrystalline or disordered films which are deposited or formed on electrically active or passive substrates (silicon, graphite, glass, plastic, ceramic or metal). The thin films are Si, CdTe, CdS, CuIn, $CuInSe_2$ and $CuInGaSe_2$. Layers of amorphous silicon (1 to 3 μm thickness) are grown by radio frequency glow-discharge decomposition process. Very-high frequency plasma-enhanced chemical vapor deposition is used to deposit amorphous silicon layers ~0.3 μm thick on plastic substrates.

We study *flexible* solar cells which can be embedded (encapsulated) in robust, fully-sealed, protected, water-proof, light-weight, compliant, non-hazardous, safe, durable and deployable fabrics. These solar cells are integrated with energy management and storage systems. Energy conversion and energy storage systems are designed, optimized and tested. System integrations and component matching issues are addressed and solved.

***Keywords*:** energy conversion, energy management, power generation, renewable energy, solar cell

1. Introduction

Significant efforts have being concentrated on low-cost, efficient, renewable, sustainable, safe and portable energy sources and systems. Recently, different photovoltaic technologies, solar cells, energy storage and power electronics solutions have being emerged [1-3]. Relevant technologies are under intensive developments.

Various enhanced semiconductors with a wide band gap were studied. For example, titanium dioxide (TiO_2) particles and TiO_2 thin films are used [3-6]. These films are deposited on a transparent conducting oxide substrates using a solgel technologies. It is found that these materials will increase the photon absorption ratio. The design of multiple-junction solar cells using III-V semiconductors with different bandgaps materials were examined [3]. Through testing, characterization and evaluations, the experimental *IV* characteristics and power curves were found [3-6]. Multiple-junction solar cells enable higher efficiency (up to ~40%) compared to other classes of solar cells. However, due to high cost, the application of multiple-junction solar cells is limited.

We study cost-effective, practical and consistent solutions. In particular, thin-film amorphous silicon *flexible* solar cells, which ensure ~10% efficiency are used. Many factors affect the affordability, practicality and effectiveness of photovoltaic systems. Performance and capabilities of photovoltaic systems are predetermined and affected by individual components. The efficiencies of different types of solar cells vary from 4 to 40% [1], while, the efficiencies of high-performance power electronics and battery charging electronics reach 90%. Different rechargeable batteries and supercapacitors are used to store the energy [2].

Though various silicon-, organic- and nano-composite solar cells were studied as potential promising solutions, limited number of solutions are found to be practical [3]. The affordability, reliability, efficiency and other criteria are application-specific. We consider completely-integrated photovoltaic systems which promise to meet industrial and military requirements and specifications including;

1. High-temperature;
2. High-humidity;
3. Explosive environment;
4. Mechanical impacts, stresses and vibrations,

as well as other harsh environmental conditions.

Design, optimization, integration and technology developments are addressed. As photovoltaic systems are considered for a broad range of applications, the affordability, safety and robustness are among the major factors. We consider *flexible* solar cells with robust nanostructured amorphous silicon (and other thin film) layers on ceramics.

For military applications, the designed portable and wearable light-duty photovoltaic power system can be used for individual combat gears, camouflage systems, sheltering devices, as well as powering stand-alone remote sensors, displays, data logging and transmission. The *flexible* solar cells can be embedded (encapsulated) in robust, fully-sealed, protected, water-proof, light-weight, compliant, non-hazardous, safe, durable and deployable fabrics.

2. PHOTOVOLTAIC SYSTEMS

A *modular* photovoltaic system, which includes various core modules, is represented in Figure 1. Though the design is performed for portable light-duty power systems, *smart grid* compliance, medium-duty systems and grid integration can be achieved. Adaptation and system enhancements can be achieved through the modular design.

The proposed photovoltaic system includes solar cells, energy conversion, energy management and energy storage units. The energy conversion unit includes;

- Controlled *buck-boost* or *boost* dc/dc PWM converter;
- Controllers, sensors and filters;
- Controllable charger which enables optimal charging profile depending on the energy storage device used;
- Signal conditioning and monitoring circuitry.

The energy conversion system is integrated with a power management and load distribution system. The energy storage unit includes rechargeable battery or supercapacitor [2].

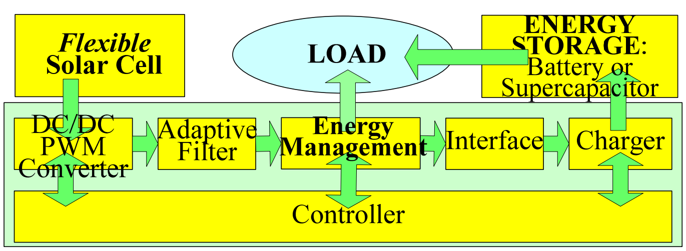

Figure 1. Modular organization of a photovoltaic and energy distribution system

3. SOLAR CELLS

Flexible thin-film solar cell are tested and characterized in the operating envelope. The images of the solar cells are reported n Figure 2. The current-voltage (*IV*) and power-voltage (*PV*) characteristics are measured and evaluated. It is found that the loading and temperature and significantly affect the *IV* and *PV* characteristics, as well as the overall efficiency. Correspondingly a *decoupling* of solar cell and *admissible* loading modes must be realized. This is performed by the energy management system using advanced control schemes.

The load- and temperature-dependent efficiency η is also examined. In particular,

$$\eta = P_{output}/P_{input} = I_{Loadutput} V_{Load}/P_{input}.$$

It is found that η depends on the irradiated power. We found that under the normal irradiation, η varies from ~5.4 to 8.4% at T=300K.

Proof-of-concept of photovoltaic systems are tested and characterized. The scalable manufacturability of *flexible* solar cells can be established. In general operational power requirements can be ensured. In addition to the scalability of solar cells, the overall adaptiveness of the proposed modular system is achieved.

Figure 2. Crystal-Si and thin-film *flexible* solar cells

4. CONCLUSIONS

We designed, optimized, tested, evaluated and characterized different photovoltaic power generation systems. Efficient energy conversion and energy management were ensured using advanced solar cells, power electronics, control and energy storage solutions. The proposed system can be used in various industrial and military applications including operation in harsh environment under rapidly changing loads.

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