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Tailored linear PV Concentrators with a Uniform Solar Flux

A thesis submitted toward the degree of
Master of Science in Mechanical Engineering

by
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Abstract

Solar energy is one of the mature renewable energy solutions and Photovoltaic (PV) systems are the most commonly used solar technology for electricity production today. The flat panel PV technology is in wide use but is still very expensive compares to conventional alternatives. One of the emerging technologies in the solar energy field, which reduces photovoltaic system cost, is concentrating systems. Concentrating technology consists on an optical system (lens or reflector) that collects the sun's irradiance from a large area and focuses it on a smaller area of photovoltaic cells. The cost of concentrating systems is lower compared to a flat PV cell, due to the use of smaller PV cell area, which is the most expensive component of the system.

Common linear concentrators for photovoltaic cells use parabolic trough reflectors. The photovoltaic module is placed at the focus point of the reflector. The radiation flux on the PV receiver is non-uniform, reducing the cell efficiency. The non-uniformity of the flux also causes local overheating and dictates non-uniform generation of electrical currents with in the cell. The non-uniformity of electrical generation generates high current far from the main electrical conductor and increases the overall cell electrical resistance. This work is for designing an optical system for linear photovoltaic concentrator system aiming to generate uniform flux on the PV receiver, and therefore improves the conversion efficiency of the system, without a significant change in the system cost.

The optical design uses the Tailoring method, which is based on non-imaging optics. The Tailoring method includes several free design parameters that can be used to generate different solutions. The design parameters defined in this work are: the concentrating ratio, the ratio between the reflector aperture to the distance of the PV module from the reflector apex, and the tailoring directions. The concentration ratio can be arbitrarily assigned up to 62 suns. The design takes into account the shadow from the PV cell and the reflector edge effect. The new geometry differs only little from a parabolic trough and thus would be very easy to manufacture. The uniformity of the flux distribution on the receiver was verified by statistical ray tracing, including a model for imperfect optics (slope errors). In order to estimate the power generated by the system, a thermal model was implemented to estimates the temperature distribution on the photovoltaic cell, and an electrical model estimating the PV cell power output under non-uniform illumination and temperature.

A comparison between the tailored designed and a standard parabolic trough concentrator was done. The tailored optics accomplished up to 23% gain in the generated electric power, and the maximum temperature on the photovoltaic is lower by 25°C. In comparison of the tailored optics against a standard parabolic trough with a homogenizer at the PV receiver aperture, a gain of 2% in electricity power generation is accomplished. When slope errors are added to the simulation, the difference between the powers generated by the systems decreases as the slope errors increase. This work shows that slope errors, have an important role in determining the system performance. Additional optical errors due to tracking and alignment may also affect the performance.

This work has shown the ability to design an optical system that concentrates sunlight according to a specified flux distribution on the receiver. In this work, the flux distribution requirement was defined as a uniform flux. Analyzing the results of this work reveals that an optimal design has to take into account the existence of surface and tracking errors, and should also allow variations in the flux as a part of the solution rather than a specified uniform flux. Performing such a redefined optimization may lead to higher gain of electrical conversion efficiency relative the gain found in this work.