DISTRIBUTIVE MPPT SOLAR CHARGE CONTROLLER

LIGHTING A BILLION LIVES: WHY SOLAR ENERGY IS NOT UNIFORM

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

As coal, oil, natural gas, and other non-renewable energy resources become scarcer and efforts to limit greenhouse gas emissions intensify, finding reliable ways to meet society's growing energy demands has become critical (Kannan, 2016). Solar energy has emerged in recent years as a frontrunner to produce large amounts of power to mitigate the energy loss from the reduction of fossil fuel use. According to the International Energy Agency, this source of energy could account for up to 11 percent of global energy production by 2050 (Dinçer, 2011). Therefore, it is as important as ever to optimize the efficiency of solar technology to maximize the effectiveness of solar energy. Maximum Power Point Tracking (MPPT) technology aims to do exactly that by optimizing the extraction of energy from solar cells.

The UVA Solar Car team plans to advance solar energy technology by developing innovative designs for a solar-powered race car. My technical project focuses on creating an MPPT device that is both cost-efficient and energy-efficient, matching or surpassing the performance of the UVA Solar Car team's current MPPT technology. This MPPT design will minimize cost and complexity with potential applications extending beyond solar vehicles to broader solar energy technologies.

To understand how MPPT innovations succeed or fail in meeting the needs of their audience, I will apply the Social Construction of Technology (SCOT) framework to analyze how the values, priorities, and demands of stakeholders have shaped MPPT technology. SCOT emphasizes that technological design is not solely driven by technical requirements but is shaped by social factors, user needs, cultural contexts, and market demands (Pinch, 1984). For example, while technical efficiency is crucial, the adoption and success of MPPT innovations also depend on factors like affordability, ease of integration, and applicability in diverse environments. These considerations are often determined by the interactions between designers and their audience, highlighting the sociotechnical nature of MPPT development. This is seen in the variance of effectiveness of solar energy adoption in rural India as part of the Lighting a Billion Lives campaign, my STS proposal topic. Because the challenge of MPPT innovation is sociotechnical in nature, it requires attending to both its technical and social aspects to accomplish successfully. In what follows, I set out two related research proposals: a technical project proposal for developing a custom cost-efficient and energy-efficient MPPT design and an STS project proposal for examining the values determining MPPT success and failure metrics used by the target audiences of solar energy technology.

Technical Proposal

One of the greatest challenges in advancing solar energy technology is the efficient use of new solar panels. A major issue is panel mismatch losses. Solar cells connected in series must operate at the same current; however, shading effects can cause current variations. This results in the total current being limited to the minimum current generated by any mismatched panel in the series, leading to significant power losses (Xu, 2010). Additionally, these mismatches can damage solar panels through hot-spot heating, a phenomenon where solar cells operate at currents exceeding their ratings, causing deterioration or melting of cells and circuitry (García, 2003). These challenges hinder the progress of solar energy systems and require innovative solutions to ensure efficient implementation.

Currently, bypass diodes are a common method to mitigate mismatch effects. Bypass diodes are connected alongside solar panels and conduct current when a panel produces less current than its neighbors, effectively "bypassing" the affected panel. However, this approach reduces efficiency, as the shaded panel's output is entirely cut off instead of contributing its reduced power (Vieira, 2020).

To address these issues, I propose designing and implementing a custom Distributed Maximum Power Point Tracking (MPPT) device for solar panel systems. A Distributed MPPT design pairs each solar panel with a buck, boost, or buck/boost converter (Alonso, 2010). These converters enable each panel, including shaded ones, to provide its maximum possible power, ensuring no panel is bypassed and improving overall energy efficiency (Bratcu, 2011).

The project's goal is to develop a Distributed MPPT controller that optimizes power transfer from multiple solar panels to a battery or load. This design will address power losses caused by mismatched currents while being cost-effective and energy-efficient. The UVA Solar Car team, the primary client, currently uses bypass diodes and expensive, inefficient MPPT controllers. The proposed design will match or exceed the performance of their current system while reducing costs and complexity. It will also be compatible with lithium-ion batteries, which the UVA Solar Car team uses. A locally hosted program will display real-time performance data to demonstrate the system's efficiency.

Key components of the design include the STM32NUCLEO-F401RE microcontroller, which will use voltage and current sensors to monitor panel outputs and adjust the duty cycle of buck-boost converters to minimize power loss. The microcontroller will communicate with integrated circuits via the I2C protocol for optimal efficiency. Each panel-converter combination will connect in series, combining their output voltages to charge a lithium-ion battery.

The system will measure metrics such as shading percentage, battery charging efficiency, and battery charge level. Data will be transmitted via PySerial to a locally hosted website, providing clear evidence that the system achieves efficient solar energy usage. This will allow our team to experimentally confirm that our design outperforms the existing MPPT systems in terms of efficiency.

STS Proposal

Many organizations have been formed throughout the years to promote sustainable energy usage, but few can claim to be as innovative as India-based international organization The Energy and Resources Institute (TERI). TERI has been a leading pioneer in innovating and providing clean energy solutions to rural and underdeveloped communities across the globe. One of their greatest campaigns debuted in 2008 with the launch of the Lighting a Billion Lives initiative, a project dedicated to bringing sustainable, off-grid solar lighting solutions in the form of solar charging stations to rural and remote areas in India (Gill, 2015). While this project had considerable funding and support from government agencies, NGOs, and international foundations, it was met with considerable resistance in various communities due to a plethora of cultural, economic, and social concerns.

Many scholars and analysts contribute these challenges in this initiative to a lack of existing infrastructure and poor entrepreneurial models. The project laid out robust criteria for the implementation of these new technologies, and establishing new systems in underdeveloped communities was bound to encounter financial difficulties (Palit, 2011). While it is certainly true that economic factors played a role in the difficulties this project faced, this analysis fails to address the full scope of this project's challenges. It is necessary to incorporate the project's intended audience as well as their needs and values to understand why this project was met with such resistance in many areas. For instance, existing analyses overlook the cultural and social perceptions of solar technology in rural areas that significantly influenced the resistance to this project.

Incorporating the understanding of cultural and social norms of rural India with the existing economic analyses of the Lighting a Billion Lives initiative provides a more comprehensive analysis of challenges this project faced. I argue that the traditional use of kerosene lamps as lighting in rural communities, the stigma of adopting new technologies that clashed with generational traditions, and the lack of convenient supporting systems for this project's solar charging stations all contributed in their own way to the resistance to the implementation of the Lighting a Billion Lives project. I claim that these trends slowed the adoption of cleaner energy usage and created an economic strain on the funding of this project.

I will use the science, technology, and society (STS) framework of the Social Construction of Technology to frame my analysis of the Lighting a Billion Lives initiative. Developed by sociologists Trevor Pinch and Wiebe Bijker, SCOT examines how technological development is a socially constructed process. It emphasizes that technologies evolve through iterations shaped by the priorities, concerns, and values of various social groups, known as relevant social groups. This framework also highlights the concepts of interpretive flexibility—the idea that different social groups can have varying interpretations of a technology's meaning and usefulness—and stabilization and closure, which occur when these groups reach consensus on the technology's form and purpose (Pinch, 1984).

Applying SCOT to this case will illustrate how overlooking the traditions and values of relevant social groups in rural India contributed to the challenges faced by the initiative. For instance, the interpretive flexibility of solar technology led to resistance as some groups viewed it as incompatible with their established norms and practices. The failure to achieve stabilization and closure for the solar charging stations reflected a disconnect between the technology's design and the social context in which it was implemented.

To support my analysis, I will draw on evidence from reports and writings addressing cultural and social norms in rural India, such as Saswata Biswas' book *Toilet Adoption in Rural India: Social Norms and Behavioural Changes* (Biswas, 2024). These resources provide precedents for understanding the influence of cultural factors on the adoption of new technologies. My analysis will explore how aligning the design and implementation of solar technologies with the values and priorities of their target audience could mitigate resistance and foster broader adoption.

Conclusion

The result of these research proposals will address the sociotechnical challenge of improving solar energy technology by combining technical innovation with an understanding of social dynamics. The technical project proposes a custom, energy-efficient, and cost-effective Distributed MPPT design that mitigates panel mismatch losses and increases the efficiency of solar panel systems. This design directly addresses a critical technical barrier to solar energy adoption and advancement, offering a scalable solution that optimizes power transfer while maintaining affordability and simplicity. Complementing this, the STS project will provide a comprehensive analysis of the values and priorities that influence the success and adoption of MPPT technologies from the perspective of their stakeholders. By using the Social Construction of Technology (SCOT) framework, this analysis will examine how relevant social groups, including the UVA Solar Car team and broader consumers of solar energy technologies, shape and are shaped by the development of new MPPT designs. SCOT's concepts—such as interpretive flexibility and stabilization—will illuminate how aligning technical innovations with social values and expectations can enhance their acceptance and effectiveness.

Together, these projects demonstrate how addressing both the technical and social dimensions of solar energy innovation can lead to more effective and widely accepted solutions. The technical design ensures high performance and adaptability, while the STS analysis ensures that these innovations are grounded in the needs and values of their intended users. This integrated approach underscores the importance of sociotechnical collaboration in advancing renewable energy technology.

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References

Alonso, R., Ibáñez, P., Martínez, V., Román, E., & Sanz, A. (2010). 2010 IEEE International Symposium on Industrial Electronics. In *Analysis of performance of new distributed MPPT architectures* (pp. 3450–3455). Bari, Italy; IEEE.

Biswas, S. N., De, I., Mudra, G., & Gupta, D. (2024). *Toilet adoption in rural India: Social norms and behavioural changes*. Routledge.

Bratcu, A. I., Munteanu, I., Bacha, S., Picault, D., & Raison, B. (2011). Cascaded DC–DC converter photovoltaic systems: Power Optimization Issues. *IEEE Transactions on Industrial Electronics*, *58*(2), 403–411. https://doi.org/10.1109/tie.2010.2043041

Dinçer, F. (2011, January). Review of *The analysis on photovoltaic electricity generation status, potential and policies of the leading countries in solar energy. Renewable and Sustainable Energy Reviews, 15,* 713-720.

García, M. C., Herrmann, W., Böhmer, W., & Proisy, B. (2003). Thermal and electrical effects caused by Outdoor Hot‐spot testing in associations of photovoltaic cells. *Progress in Photovoltaics: Research and Applications*, *11*(5), 293–307. https://doi.org/10.1002/pip.490

Gill, B. (2015). Lighting a billion lives: A local approach to a global problem. *Sustainability: The Journal of Record*, *8*(5), 245–253. https://doi.org/10.1089/sus.2015.29019

Kannan, N. (2016, September). Review of *Solar energy for future world: - a review*. *Renewable and Sustainable Energy Reviews*, *62*, 1092–1105.

Palit, D., & Singh, J. (2011). Lighting a Billion Lives – Empowering the rural poor. *Boiling Point*, (59), 1–4.

Pinch, T. J., & Bijker, W. E. (1984). The social construction of facts and artifacts: Or how the sociology of science and the Sociology of Technology might benefit each other. *Social Studies of Science*, *14*(3), 399–441. https://doi.org/10.1177/030631284014003004

Vieira, R., de Araújo, F., Dhimish, M., & Guerra, M. (2020). A comprehensive review on bypass diode application on photovoltaic modules. *Energies*, *13*(10). https://doi.org/10.3390/en13102472

Xu, Q., Song, J., Bian, H., Yukita, K., & Ichiyanagi, K. (2010). 2010 Asia-Pacific Power and Energy Engineering Conference. In *Analysis of photovoltaic array performance under shaded conditions* (pp. 1–4). Chengdu, China; IEEE.