DISTRIBUTED MAXIMUM POWER POINT TRACKING PROOF OF CONCEPT FOR UNIVERSITY OF VIRGINIA SOLAR CAR TEAM

(Technical Paper)

AN INVESTIGATION OF THE AUTOMOBILE INDUSTRY CARBON EMISSIONS AND EXPLORING WAYS TO REDUCE EMISSIONS

(STS Paper)

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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

One of the main sources of carbon emissions is vehicular transportation (Teng et al, 2024). To counteract this issue and promote sustainability, public transportation projects and clean energy vehicles are imperative. Cleaner transportation faces several obstacles including cost and power efficiency. Comello et al. (2021) compares the costs of electric and fuel powered buses when taking different routes. This shows that there are various optimizations that can be done in public transportation systems to make electric vehicles more viable for long term use. Another issue in the fossil fuel dominated energy economy is the necessary capacity of renewable energy solutions that would be required to replace it. Tian et al. (2023) addresses this stating that the needs for renewable energy sources are only increasing and becoming more difficult to replace non-renewable energy.

To address these obstacles to reducing carbon emissions from forms of transportation, social and economic aspects must be examined. According to Capareda (2019) the initial costs for implementing renewable energy sources are higher than non-renewable energy; however, the cost in power once the system is implemented is highly competitive with non-renewable sources. Sperling and Cannon (2007) highlight how the United States passenger vehicle industry has focused on increasing size and performance as opposed to how several European nations have focused on fuel taxes that have led to more fuel-efficient vehicles and less overall emissions.

Solar power solutions tend to have lower power efficiency compared to environmentally damaging resources such as fossil fuels. To increase the power efficiency of solar panels, they are often paired with a Maximum Power Point Tracking (MPPT) controller. These systems tend to use a single controller that regulates the current and voltage output by an array of solar panels and find the maximum power point by using algorithms based on sensor data. Solar panels produce a current and voltage that can vary depending on partial shading conditions, orientation, and faulty photovoltaic components requiring control systems to reduce power loss (Alharbi et al, 2023). Distributed MPPT controllers are an emerging technology that utilizes voltage and current regulation at each panel as opposed to a single controller for the entire array. This can lead to greater power yield and is the focus of this technical research. The Science, Technology, and Society (STS) research will primarily focus on reducing transportation carbon emissions by optimizing existing transportation infrastructure and exploring ways to implement more public transportation as well as making environmentally cleaner vehicles.

## Technical Discussion

My technical project aims to improve the existing solar panel system on the UVA Solar Car Team. The Capstone team will construct a proof-of-concept distributed MPPT controller consisting of printed circuit boards (PCBs) and a microcontroller.

The UVA Solar Car Team currently uses two solar panel arrays in a series, each connected to an MPPT controller. These are then connected in parallel to the load. Solar panels when put in a series are limited by the panel with the lowest current due to Kirchoff's Current Law. To mitigate this, the Solar Car Team uses bypass diodes that allow the system to effectively skip solar panels that are producing a lower current. The main issue with this design is the power lost by ignoring the panels that have lower currents. The proposed design will address this problem by utilizing a modular distributed MPPT system that will interface with each of the panels and optimize the system for more power output.

There are several architectures for distributed MPPT systems such as differential power optimization and cascaded DC-DC power optimizers (Shenoy et al, 2013). Differential power optimization uses differential converters between each of the panels to supply current for the currents of all the solar panels in an array to match and then are regulated by a central MPPT controller. Cascaded DC-DC power optimizers make use of buck, boost, or buck-boost converters to match the output currents of each of the solar panels and find the maximum power point of each of the solar panels to increase power output. MPPT algorithms that exist for central controller systems will not be applicable to distributed MPPT systems, thus requiring more complex algorithms to track the maximum power point and calculate changes that need to be fed into the system to extract maximum power (Pho et al, 2022).

Our design will focus on implementing a cascaded DC-DC power optimizer making use of buck-boost converters because of the overall easier design and less costs for manufacturing. The Solar Car Team currently uses MPPT controllers designed by MG Energy Systems that cost $1,720 each. One of the goals of this project is to design a modular PCB for each panel that interfaces with a microcontroller. Another goal is to have the distributed MPPT system perform better than a single MPPT controller by performing tests to verify the higher power output.

The microcontroller chosen for our project is the STM32F071RE debugger board because it allows for easy testing and a similar board is used in a required introduction to embedded systems course alongside the STM32CubeIDE an environment for programming software that is flashed to the board. This will use a form of peripheral communication to retrieve sensor data as well as regulate the output of the buck-boost converters. To reduce the overall number of wires when communicating between devices, inter-integrated circuit (I2C) communication is used by configuring the peripheral device addresses of each of the devices. This allows the microcontroller to send address data over a data bus connected to each of the devices to determine which devices it is communicating with and transfer data. As we progressed through the project, an oversight discovered was that most I2C devices only allow us to switch between a few addresses and thus for improved implementation, a communication method such as serial peripheral interface (SPI) communication is more useful, utilizing an external multiplexer and requiring more wiring. The PCBs were already designed for I2C communication and will still serve proof-of-concept, but for full integration into the Solar Car, it would require configuring SPI communication.

For our PCB design, we chose to use several integrated circuits (ICs) to simplify the design and offload the complexity to the software side. The ICs chosen are the TPS552800 (buck-boost converter) to regulate the output of each panel and ACS37800 (voltage and current sensor) to measure the voltage and current output of each panel to adjust the output of each panel in the system. These both support I2C communication and have acceptable voltage and current rating for our design. Another note for the PCB is that relative grounding will be used to meet those voltage ratings on the ICs.

As for software, a website using the Django framework will be used to display metrics communicated from the microcontroller. Several algorithms as well as a voltage sweep of the panels will be used to verify our design. Some of the algorithms that will be implemented include Perturb and Observe and Hill Climbing. The microcontroller will be programmed to be able to switch between the various algorithms using universal synchronous asynchronous receiver transmitter (USART) communication.

## STS Discussion

Climate change is a prominent contemporary issue with large increases in carbon dioxide in our atmosphere that is coupled with the growing population and deteriorating natural world

(McNall, 2011). Sperling and Cannon (2007) state that the population is projected to increase to 9.1 billion by 2050 according to the United Nations and will also lead to an ever-increasing energy demand. This highlights the tight coupling between modern social issues of population growth and greenhouse gas emissions that requires a review of current systems and infrastructure while also exploring methods to improve the current state of the fuel economy.

Currently the United States is projected to lag in improving the state of the fuel economy and emissions because of overall lower standards. California has been the main proponent of improving the improvement of motor vehicles and has led to the adoption of its standards by several other states (Sperling & Cannon, 2007). Gerrard et al (2022) also highlights the increasing action of regulation at the state level with inaction at the federal level. This brings to the forefront that emissions regulations face hurdles at the local and national levels and can also require different regulations based on cultural and regional backgrounds.

In 2008, several states signed the Regional Greenhouse Gas Initiative (RGGI leading to more expectation for greenhouse gas emissions regulations at the federal level (Gerrard et al, 2022). Eventually under the Obama administration, a clean power plan was established sanctioning the RGGI and California's efforts. However, there was a lot of backtracking on efforts under the Trump administration.

My STS research is about understanding what the causes of climate change in the transportation sector are and how the global and local states of the world are impeding efforts to 7 cleaner energy solutions and reduce emissions. The STS framework used to conduct this research will be actor-network theory. This is universally applicable because of the many factors including social, economic, and political factors as well as global relations that are involved in improving transportation-based emissions. There is a need for nations to recognize the interdependence of nations to combat climate change and require extensive cooperation and regulation, which will require overcoming global political and economic hurdles.

## Conclusion

The technical project will be completed with a PCB integrated with a microcontroller and software that is able to control a distributed MPPT system to power a load using several solar panels. This will involve a demonstration of the working product using metrics displayed on an offline website by communicating data between a computer and microcontroller. The UVA Solar Car Team can then potentially adapt the working technical project to increase the power throughput of their solar panel arrays. The STS research will develop a thorough understanding of the problems the world is currently facing due to climate change, its causes, as well as global and local politics that are impeding the progress required to address emissions. This will involve exploring different solutions to the existing system and understanding the underlying actors and networks to overcome climate change.

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