Maximum Power Point Tracker
Development Project

Project Plan

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Project Abstract

The goals of this project are to research and develop efficient, economic, and reliable peak power point trackers for photovoltaic arrays. The maximum power point trackers operate the photovoltaic array so that the array is operating at its most efficient voltage, independent of the system voltage to which the system is connected. Currently available commercial trackers are not well suited to our application because they are designed for large stationary arrays where the weight, cost, and response time to lighting changes are not nearly as important. Also, most currently available trackers have limited flexibility in terms of the ratio of array input voltage to system bus voltage due to their design. This is a hindrance to us, as our array and system voltages are constantly changing due to many factors, such as the state of charge in the batteries, the load on the car, and the light being taken in. Because our project involves many constantly changing variables, a better, faster, more flexible power tracker design is necessary. Our goal in this project is to engineer a tracker that not only meets the needs of our solar race vehicle, but also is equal to or better than commercially available designs and flexible enough to be used in a host of other applications.

Problem Statement

In applications where photovoltaic arrays are used to provide energy, maximum power trackers are used to correct for the variations in the current-voltage characteristics of the solar cells. As one can see in the typical silicon cell I-V curve in Fig. 1-1, as the output potential of the string rises, it can produce significantly less current. This curve will move and deform depending upon temperature, illumination, and consistency of cell quality in the string. For the array to be able to put out the maximum possible amount of power, the either the operating voltage or current need to be carefully controlled. This maximum power point is seldom located at the same voltage as the system is operating at, and even if the two were equal initially, the power point would quickly move as lighting conditions and temperature change. Hence, a device is needed that finds the maximum power point and converts that voltage to a voltage equal to the system voltage.

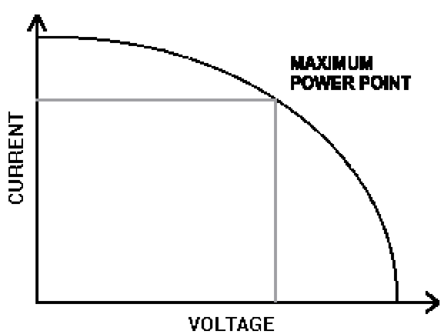

Figure 1-1 - Sample Si Solar Cell Current-Voltage relationship

The devices that perform this function are known as Maximum Power Point Trackers, also called MPPTs or trackers. Most, if not all, designs for these consist of three basic components: a switchmode converter, a control and tracking section, and an auxiliary power supply. The switchmode converter is the core of the entire supply. This allows energy at one potential to be drawn, stored as magnetic energy in an inductor, and then released at a different potential. By setting up the switchmode section in various different topologies, either high-to-low (buck converter) or low-to-high (boost) voltage converters can be constructed. Normally, the goal of a switchmode power supply is to provide a constant output voltage or current. In power trackers, the goal is to provide a fixed input current, such that it holds the array at the maximum power point, while allowing the output to match the battery voltage. This section tends to be problematic on currently available trackers, as few of the more common boost type converters have output voltage limiting. In the event that the load becomes disconnected, output voltage essentially rises without bound, leading to the destruction of the power section.

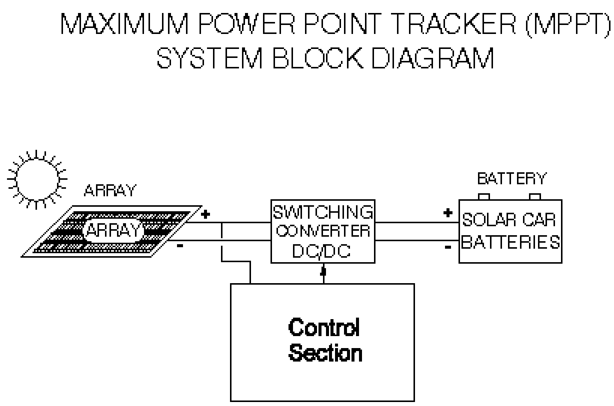

Figure 1-2: Simple tracker block diagram

The control section, then, by reading either voltage and/or current back from the switching converter, is designed to determine if the input is actually at the maximum power point and adjust the switchmode section such that it is. Usually, this is either done by using 80% of the array's open circuit voltage as a guess for maximum power point, or by maximizing the current going through the switchmode converter section. While conceptually very simple, the actual implementation becomes extremely complex because of the wide range of variables to be dealt with as well as the high currents and large amounts of electrical noise. This is normally the most reliable section, with few major faults. However, the algorithms the control section operates under need to be tuned to either a mobile or a stationary application.

The auxiliary power supply is really part of the control section, being responsible for taking the high voltage being produced by the array and converting it into the +12V and +5V usually needed by the control logic. These, in the past, have been problematic because of the loading characteristics of the array under early morning sun. When the auxiliary supply would try to start, it would draw excessive current and the array voltage would drop too low, and then the whole process would repeat, often leading to self-destructive oscillations.

For Iowa State University's Team PrISUm Solar Car Project, reliable, efficient, specialized trackers are an important part of an overall winning car design. The commercial trackers that are currently available do not meet all of the needs of this harsh mobile environment. Most respond erratically to fast changing array conditions, such as passing under the narrow shadows of tree branches or the quick-moving shadows of passing cars. Team PrISUm's experience has also been that the currently available trackers, including both those developed previously here at Iowa State University and commercial models, are problematic on even the best of days and are far from ideal for use on a modern solar-electric vehicle. Common problems included destroyed output stages due to the lack of built-in overvoltage protection, unreliable startup in the morning, lack of telemetry data available directly from the tracker, reliability problems in a such a rugged environment, and inefficient operation.

The goal of this project is to develop a maximum power point tracker explicitly for use on solar race vehicles that are equally or more efficient compared to commercial tracker models, are more cost-effective than models produced to date, and meet Team PrISUm's application-specific requirements.

Design Objectives

Because of the specialized application that these trackers are intended for, the design requirements tend to be unique and far overrated for most other typical applications.

- **Track power point with an algorithm suitable for mobile arrays**
  As discussed earlier, fast-moving shadows can cause problems with many available trackers because they are mainly designed for stationary applications. Fast shadows cause these trackers to lose the maximum power point momentarily, and the time lost in seeking it again, because the point has moved away quickly and then moved back to the original position, equates to energy lost while the array is off power point. On the other hand, if lighting conditions do change, the tracker needs to respond within a short amount of time to the change to avoid energy loss.

- **High efficiency**
  Commercial trackers have switching efficiencies approaching 98%. In order for our trackers to be feasible for use as an alternative to commercial units, the new design needs to meet this same throughput efficiency. In addition, by using low power design techniques on the control side of the tracker, it should be possible to lower the quiescent power drawn off the array to keep the power trackers running. In turn, this will equate to more net usable energy into the car.

- **Electrical characteristics**
  There is still some amount of uncertainty as to the exact array and system voltages on Team PrISUm's next car, because the selection of batteries and motor are yet to be finalized. It was decided that the next trackers should operate on array voltages from 0-200V and main system voltages from 0-150V at up to 10A of output current, such that no matter what voltages are picked, they will be within the design boundaries.

- **High reliability under adverse conditions**
  Solar racing vehicles are the epitome of adverse operating conditions. Under typical operating conditions, temperatures inside the car can reach a sustained 50°C, mud and water entering the shell are common, large amounts of shock due to highway imperfections and stiff suspension can destroy electronic hardware quickly, components are often accidentally thrown around and abused during maintenance, and system voltage and load often changes very rapidly, causing high voltage spikes from line inductance. All these add together to create a unique environment where custom and commercial

electronics packages alike are extremely likely to fail if not designed explicitly for the conditions at hand.

- **Specialization**
  Because of the fact that these trackers will be used on a vehicle which is not yet entirely designed, flexibility is a must. Digitally-configurable options for tracking speed, output voltage limiting, bus address configuration, and output current limiting are essential such that the tracker can work effectively with whatever system voltage and battery management hardware is implemented on the final race vehicle. In addition, the tracker needs to talk on the vehicle's proprietary RDB (Random Differential Bus) telemetry and control communication network.

- **Other concerns**
  Since one of the key design elements of these race cars is the overall car weight, minimum weight needs to be included as a design goal. Obviously, because of the critical nature of power trackers in transferring array energy to the car as a whole, efficiency is not to be traded for weight, but all things being equal, minimization of weight is a vital concern. To emphasize the importance of this, estimates from simulations run show that each pound of weight added to the car adds an additional 0.8W to the power expenditure needed to push the car down the road. The goal is to keep the total weight of each tracker to 2 pounds or less.

Proposed Technical Solution

There are several alternatives that were, and in some cases, still are being considered in the design of the next generation of power trackers for Team PrISUm. Based on performance evaluations of one of the original trackers developed at ISU by Dr. Potter and Paul Dorweiller and of one of the Solectria™ / Brusa™ commercially-available trackers, we were able to arrive at a few decisions.

The most important of these decisions was that a digital control and tracking system would be used to operate these new trackers. The alternative was to go with a completely analog system, which would have yielded faster response times to array changes, but also had several significant shortcomings. The original intent was to make these trackers configurable on the fly, and this would be exceedingly hard with an analog system, considering that all telemetry and control information on the next car is intended to travel across a proprietary digital packetized network known as RDB. Thus, there would have had to have been at least one microcontroller on board regardless to handle communications, configuration, and telemetry. Secondly, microcontrollers were available that consumed only 1.8mA running at 3.579545MHz (the colorburst frequency of a standard NTSC video signal, the most commonly used clock frequency on the next race car, due to the high availability of inexpensive crystal oscillators at this frequency) - just a few op-amps in an analog tracking section would have quickly used up the same amount of energy. Digital control algorithms could also be adjusted and tuned to match additional performance data as it was obtained. With an analog tracker, the proper algorithm would have essentially needed to be known first before design could even proceed. With only limited data on array performance on the race due to a dead telemetry system, developing the proper algorithm for a moving array would have been extremely difficult in the time allotted, if not impossible.

A digital design is not without limitations, though. Because of the ultra-low power components being used and the high amount of electrical noise in the immediate area (largely due to the switching converter), high-accuracy analog-to-digital conversions will be difficult without very careful bypassing and noise suppression. Also, because no matter how carefully things are designed, the possibility of transients on the power rails exists; random processor lockups and resets are scenarios that must be looked at and handled effectively.

The choice of microcontroller was one of the next decisions made. For the most part, the rest of the vehicle will be based around the Microchip PIC 16XXX series of microcontrollers for three reasons: cost, reliability in adverse environments, and ready availability of development tools. In the new trackers, at least the communications processor with RDB would have to be a PIC, because a PIC with interface and bus arbitration code has already been designed as a universal RDB transceiver. With the low power consumption of these devices (less than 2mA under our conditions and clock speed) and the ample amount of instructions per second, the decision was made to go ahead and use them for the main tracking and control processor, as well.

For telemetry, the client has decided that at the very minimum the next trackers need to be able to provide digital measurements of the array (input) voltage and current as well as the battery (output) voltage and current. In addition, we intend to at least provide information about the status of the switchmode converter and a self-diagnostic mode for the tracker as a whole to aid in diagnosing vehicle failures.

One important upcoming decision that will need to be considered is the exact switching topology to be used. This is largely dependent upon the size of the battery pack, the chemistry of battery used, the size of the photovoltaic array itself and the voltage it lends itself to for convenient solar cell string lengths. Pure buck (high voltage array to low voltage battery) and boost (low voltage array to high voltage battery) topologies have been considered, as has a combination that is capable of doing either. In addition, flyback design trackers have been considered that would provide either effectively bucking or boosting while providing electrical isolation between the array and battery. This could be an important point, as at least one array panel was destroyed in Sunrayce '97 because the tracker's safety features failed and the batteries were allowed to feed back through the array.

Design is only one consideration of the technical solution - testing, debugging, and product proving is the other major consideration. Reliability is of the utmost concern to our client, because only minutes separate the top teams at Sunrayce and tracker failures could cost the team precious time sitting and waiting for repairs. Since PrISUm ExCYtor (Team PrISUm's 1997 race vehicle) will be out on test runs between May 11 and May 24, the decision was made by the design team to have a preliminary prototype of this new tracker done by the end of the semester. This will allow us to place it on an actual working solar race vehicle and examine how the new design performs under the rigors of the thermal, electrical, and mechanical stresses of vehicle operation. Our intention is to obtain on-the-fly data for not only our tracker, but for a few other commercial types, so that we might compare them and have quantifiable results on how the new design measures up to our design goals as well as to other trackers.

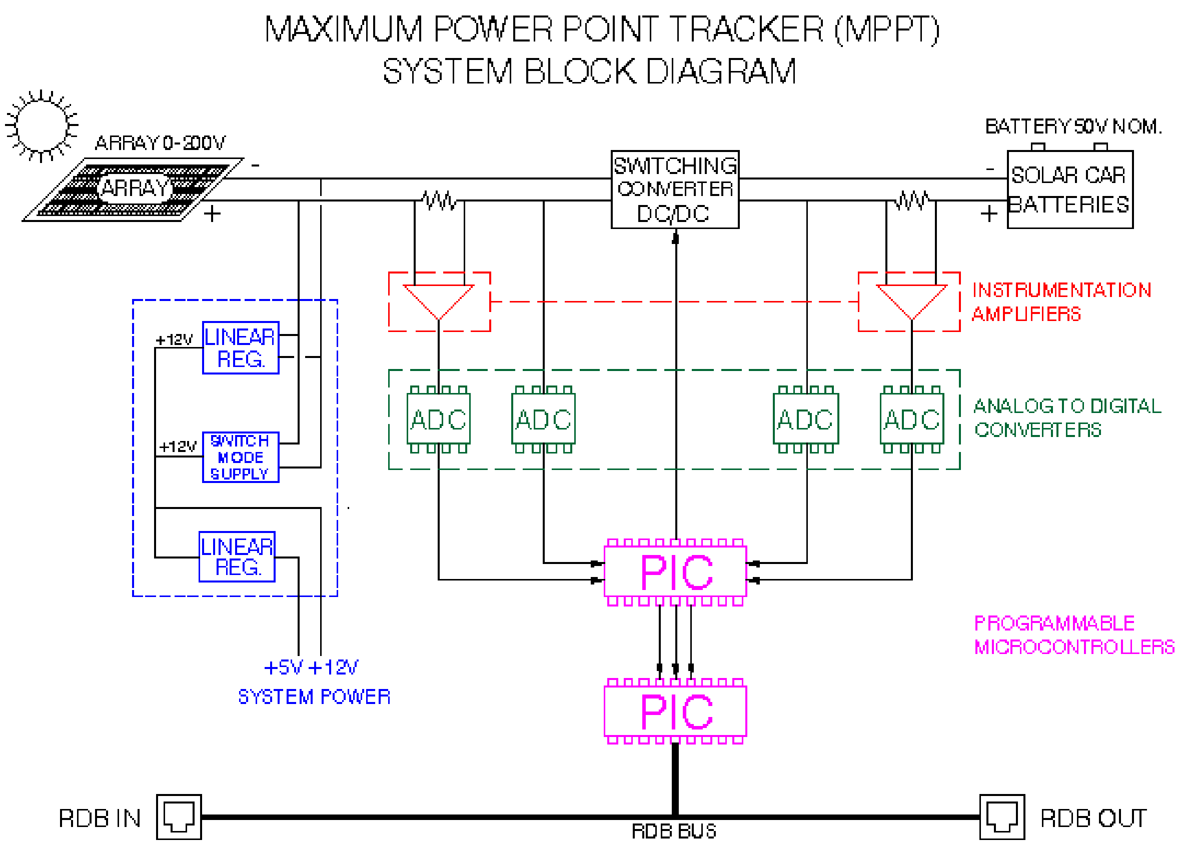

Figure 3-1: Preliminary diagram of the design being considered for the next generation of power trackers .

Our current semi-detailed block diagram for the next generation of power trackers is shown below, in figure 3-1.

In this view of the next tracker, the reader can see that all the key components are there - there is a block for the switching section, and the control system is more explicitly laid out. This is largely a result of what was stated above - the exact topology for the switching converter is still a undecided, as it depends on several specifications about the next race vehicle, which should be decided shortly. In addition, the auxiliary power supply is shown explicitly (in blue). There will be a linear supply for low input voltages and startup, and a switchmode supply to provide auxiliary power as the array input voltage continues to rise. This allows early startup in the morning, when there is not enough energy to start the switchmode supply but there is enough to run the PIC, and it will allow the processor to control the transition to switchmode when voltage levels rise to such a point that it becomes possible to do so.

The control section is based around four discrete serial output analog-to-digital converter ICs, which will more than likely be micropower 12-bit converters from either Linear Technologies or Maxim. Two of these A/D converters read the output of instrumentation amps positioned across high accuracy shunts, so as to read input and output current, and the other two read the input and output voltages through a resistive divider. Although there are PICs available with built-in analog-to-digital conversion, the decision was made to go with external converters for two reasons. The first is that all readings can then be simultaneous, which is important for the tracker to find input and output power since there will be large fluctuations on both sides over time. The second reason is that the internal ADCs of the PIC 16C73 series have only 8-bit accuracy, a fixed-reference voltage, and not nearly the conversion speed or common-mode noise immunity. In all, a better measurement could be obtained using external 12-bit converters, possibly placing them near the source of measurement to eliminate long analog lines that will act as antennas for electrical noise.

There will also more than likely be two independent processors, both running at colorburst frequency (3.579545MHz). The uppermost PIC in the diagram will be for collecting data and controlling the switchmode section of the supply, whereas the bottom PIC is exclusively an RDB transceiver. This was done because RDB is a timing-sensitive application that cannot wait for an interrupt to service the switchmode section or any other delay.

The prototype we intend to have done for testing in May will follow this general diagram. Based on what we learn from that, revisions to the individual sections may be made, but the general block diagram of the system and how it interacts is not anticipated to change by much.

Proposed Budgets

The budget for this project is a bit unknown yet. Team PrISUm will help fund the essentials, but a proposal was submitted to the Iowa Energy Center for additional funding to aid in maximum power point tracker research and development. The results of this effort should be known approximately a week after this project plan has been submitted. The financial budget below reflects only baseline costs to us to build the needed trackers for the car. Any additional funding will allow additional features and needed improvements, such as backup trackers, professionally-printed circuit boards, and possibly experimentation with surface-mount versions to help minimize weight and size.

For the different phases of our project:

Phase	Description	Weeks (if applicable)	Cost in Dollars	Cost in Man-hours
Research	Time spent reading, examining current trackers, learning, and experimenting. Only expense is copying fees	3	$10	90 hours (30 hours per person)
Design	Time spent calculating, brainstorming, finalizing, and limited prototyping	3	$0	90 hours (30 hours per person)
Prototype	Time spent constructing, debugging, and modifying the first prototype	5	$100-150	120 hours (40 hours per person)
	Construction of Poster	0.5	$25	15 hours
	Writing of Design Review Document	0.5	$0	15 hours
Testing and Integration	Summer testing of prototype on the car, debugging of prototype	2	$50	80 hours (40 hours per week)

Debugging	Finding and fixing the errors revealed by summer testing	6	$50-100	180 hours (60 hours per person)
Reprototyping	Building a new prototype for additional testing, and testing	4	$100-150	120 hours (40 hours per person)
Debugging #2	Debug the second prototype, arrive at a finished product	2	$50	60 hours (20 hours per person)
Documentation	Produce the final report	2	$25	60 hours (20 hours per person)

Proposed Schedule

People Involved

Client

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