# The Tier Solar Controller

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## 1 Introduction

Local electricity generation is one of the key challenges of technology for developing regions. Although we were driven by the need to power rural connectivity solutions, the solar controller described here makes sense for any remote ICT project with power needs up to about 100W, which includes most home solar systems, as well as single PC projects, such as kiosks.

The intended use of this board to provide reliable electricity for our WiFi-based long-distance (WiLD) links, particularly relay points. The relay point may be in the middle of a remote area where no grid power is available. Furthermore, even in areas served by the grid, power is often unreliable.

To address the issue of providing power to the wireless routers, we focus on solar power. Depending on the situation, solar power can be the only source of power or can complement existing power from the grid.

The main components of a solar power setup (solar panel, battery and charge controller) are readily available, and can be used to supply power for wireless routers. However, current designs did not meet our goals in terms of cost, ease of use, and remote monitoring.

With current available technologies, one has to put together several pieces of hardware to come up with solar power setup for wireless routers. Having several individual pieces of hardware for a setup increases the complexity and expense of the setup. Ideally, setups should have the least components from an ease of use and cost standpoint. The solution presented here combines the peak-power tracker (PPT), the charge controller, power of ethernet (PoE), and remote monitoring into one small board, with a single unit cost of US$50 (so far).

In addition to reduced cost, this board is very easy to use: just connect the panel and the battery, and the power flow out the PoE port to the wireless router. Using the ethernet port, we can query the status of the panel and the battery for remote monitoring.

Finally, the board pays for itself! First, the peak power tracker achieves about 15% more power out of the solar panel (compared to a direct connection). Second, the charge controller should roughly double the lifetime of the battery, by ensuring proper charging and discharging. In addtion to the financial benefits, doubling the battery life halves the considerable health and environmental problems of lead-acid batteries.

We next present the design, following by details on its capabilities and limitations.

## 2 Functional Blocks

The board mainly functions as a charge controller and a system status monitor.

The board has four major blocks: the microcontroller block, the voltage and current sense block, switch-mode power conversion block, and the Ethernet and serial ports block.

The microcontroller block consists of the PIC16F88 and associated support circuits for the PIC. The PIC16F88 microcontroller coordinates the different functions of the board. It talks to the voltage and current sense circuits to determine the voltages and currents

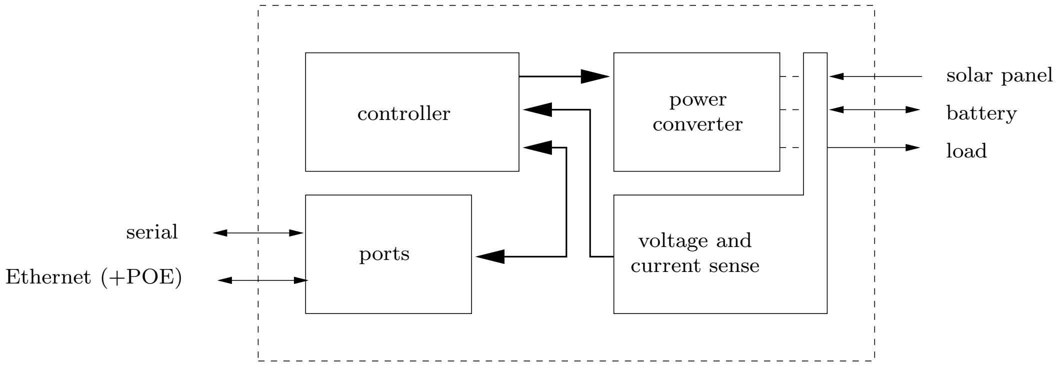


Figure 1: System Block Diagram

of the solar panel, battery and the load. It also interfaces to the switch-mode power converter to set the appropriate power conversion factor, and the Ethernet and serial ports to report system status.

The voltage and current sense block is built around the PIC's analog-to-digital inputs and the LM3813 current-sense ICs. Voltage divider circuits are implemented to convert the solar panel, battery and load voltages to levels compatible with the PIC A/D inputs. Currents for the solar panel, battery and load are sensed directly using LM3813-10 current gauges. Both the PIC A/D converter and LM3813 current sense have 10-bit conversion resolutions.

The switch power conversion block is built around the LTC1624 switching regulator controller. The power converter is designed to switch among different conversion ratios in order to achieve maximum power point tracking. Depending on conditions such solar intensity and battery voltage, the PIC microcontroller sends signals to the power converter to adjust the conversion ratio so as to extract maximum power from the solar panel. The power converter shows typical efficiencies of 95%. With the use of maximum power point tracking, we observe total power gains of up to 15% compared to a simple direct panel-battery connection.

The Ethernet and serial ports block provides external Ethernet and serial interfaces to enable the board to report system status to the router. The Ethernet interface is built around the ENC28J60 SPI Ethernet chip; the interface operates at 10 Mbps full-duplex. The serial interface is standard RS-232 at 19.2 kbps.

# 3 Capabilities

As a whole system, the board functionality can be categorized broadly into charge control and system monitoring. The charge control aspect revolves around the solar power conversion and battery charging, while system monitoring aspect is concerned with sensing the state of the power system and reporting it to the router.

## 3.1 Charge Controller

The capabilities associated with the charge controller are

1. Maximum power point tracking
2. Low voltage disconnect

3. Trickle charging

With maximum power point tracking, the system optimizes the power conversion between the solar panel and battery (and load). The PIC microcontroller determines the optimal conversion setting depending on the voltages and currents of the solar panel and the battery. Voltages and currents are read every 250 $ms$. The microcontroller then tells the power conversion block to do power conversion at the determined setting. Using maximum power point tracking, overall gains in power of 15% have been observed compared to a simple solar panel and battery direct connection. Usual charge controllers for low power systems are essentially direct connect types.

The additional gain in power translates to more power to charge the battery and/or more power available to the router. This could factor in directly to having longer battery back up time and being able to set the router to higher power settings. In terms of the overall solar power setup, smaller solar panels can be used which means lower cost since panels are usually the most expensive part of the solar setup.

Aside from power tracking, the board also performs low voltage disconnect and trickle charging. Since lead-acid batteries are typically used in solar power setups, it is important that the battery is not deeply discharged nor overcharged to prolong battery life.

Low voltage disconnect prolongs battery life by not allowing the battery to get deeply discharged, it disconnects the router (and the load) automatically when battery voltage falls below a preset threshold. With the microcontroller continuously sensing the battery voltage, it can immediately disconnect the router when voltage drops below critical levels. The router is also automatically powered up when the battery voltage is significantly above the threshold voltage. Low voltage disconnect threshold is currently set at 11.3 $V$. The connect threshold is set to 0.5 $V$ above the disconnect threshold to have some hysterisis and prevent the system from unnecessarily reconnecting and then disconnecting the router.

Trickle charging enables the board to charge the battery to maximum capacity while not overcharging it. With the switch-mode power converter, the charging voltage to the battery can be finely varied to enable trickle charging. Trickle charging is currently set to be enabled when the battery voltage is 14.3 $V$.

## 3.2 System Monitoring

The capabilities associated with sytem monitoring are

1. Voltage and current sense for solar panel, battery and router.
2. Ethernet and serial reporting
3. Power over Ethernet (PoE)

Voltages and currents for the solar panel, battery and router are continuously monitored every 250 $ms$. Voltage is sensed using the internal A/D converters of the PIC microcontroller. Voltage monitoring range is from $0 - 36$ $V$ with 10-bit resolution. Current is sensed using three separate current gauges which report current magnitude as well as current flow direction. Knowing the current flow direction is especially important in monitoring whether the battery is charging or discharging. The current sense circuit is rated up to 10 A with 10-bit resolution.

The voltages and currents sensed are used by the PIC in power calculations to implement power tracking, for low voltage disconnect, and for trickle charging. The voltage and current values are also reported through the the Ethernet and serial ports. In addition, the power conversion setting and trickle charge status are also reported.

With the current implementation, Ethernet reporting begins only after receiving an ARP request for a specific range of addresses. This allows the board to determine the subnet it is on and report on this subnet appropriately. Basically, an ARP request for the address x.y.z.123 will set the board to use x.y.z subnet in its reporting. The system status is reported by the board using ARP replies to nine consecutive IP addresses starting at address x.y.z.123. The data is reported using the last two bytes of the MAC addresses for the mentioned IP addresses. Using the ARP replies and the last two bytes of the MAC addresses to communicate the system status report simplifies extracting the reported data. A short tcpdump and awk script is all that is needed to get the data from the board to the router.

To give the system maximum flexibility, all data reported through the Ethernet is similarly echoed through the serial port. Additional reports are also sent out the serial port for debugging during initial system setup.

Since the board was designed to simplify wireless router setup with solar power, having power over Ethernet is crucial. The onboard Ethernet jack supplies 12 $V$ across pins 4/5(+) and 7/8(-) to implement PoE. The PoE pins are tied to the low voltage disconnect circuit, which powers down the router if voltage drops below the critical level.

# 4 Advantages of Using the Board

The clear advantages of using the designed board for wireless router setup with solar power are

1. Simplicity of setup
2. Flexibility in managing power
3. Intelligent battery management
4. Cost

With typical wireless deployment already consisting of several components (router, antennas, connectors, cables) and solar power setup adding to this list, simplifying the deployment of the entire system is critical to a successful deployment. Definitely, the less parts the system has, the easier to deploy and less things can go wrong.

Using the board simplifies the setting up of the solar power and wireless router system. One only needs to connect the solar panel and battery to the board, then PoE would be readily available through the onboard Ethernet jack. This level of integration is rare in devices found in the market today.

The periodic reporting of system status to the router allows the router to manage power usage of the wireless link. Managing power is critical in applications where solar may be the only source of power and reliable operation is required. Wireless routers consume different amounts of power depending on variables such as the link speed and the amount of traffic. With the router having a complete picture of the energy status of the whole system, it can decide on how to set the link parameters appropriately to optimize the energy usage.

With trickle charging and low voltage disconnect, the board intelligently manages the battery. This leads to longer battery life. The board senses the battery voltage and switches to trickle charging at a preset threshold voltage which keeps the battery at near 100% capacity without overcharging. Also, the board disconnects the load when a minimum battery voltage threshold is reached. The programmed low voltage disconnect threshold setting allows for an 80% depth-of-discharge (DoD). Without low voltage disconnect, the battery goes to 100% DoD which shortens battery life significantly. For sealed lead-acid batteries, [1] shows that the total number of charge-discharge cycles for 80% DoD is twice compared to 100% DoD. This translates to twice the battery life in solar setups where the battery goes through a charge-discharge cycle daily.

Cost is especially important for deployments in rural and developing regions. The board costs around $50 to construct which is about the cost of a basic barebones charge controller. Charge controllers with power tracking are typically in $300 and above level, and do not offer PoE or status reporting via Ethernet. Thus, using the new board incurs no additional cost over a basic solar power setup with a simple charge controller. Furthermore, at no additional cost, the new board provides power tracking, low-voltage disconnect, trickle charging, and system status reporting.

The completed board is shown in Figure 2. Board dimensions is 7.6 *cm* x 7.6 *cm*.

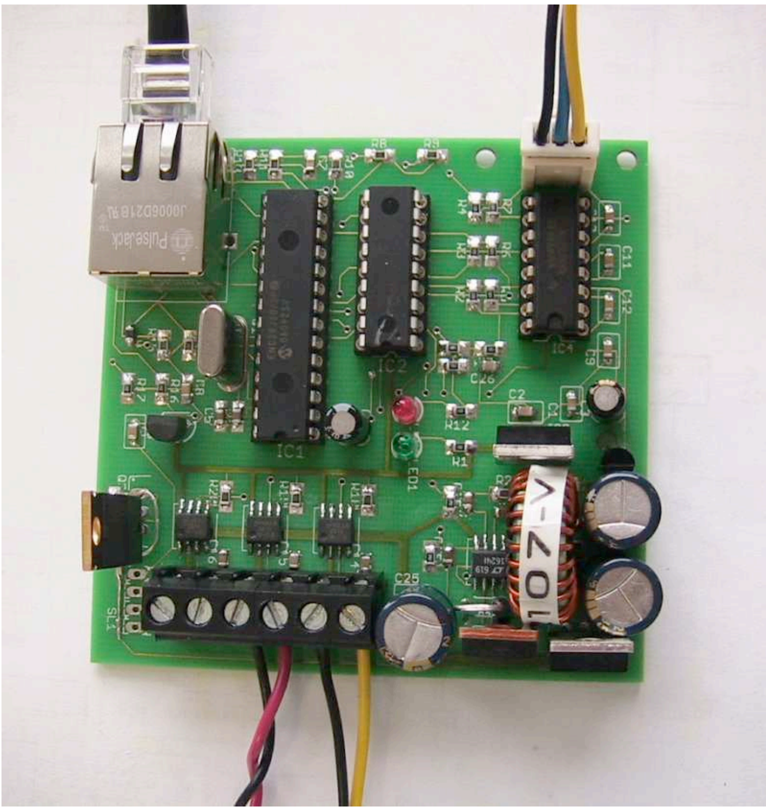


Figure 2: Completed Board

# 5 Operating Conditions and Absolute Ratings

The board uses standard commercial grade integrated circuits and components. Operation is then guaranteed at temperatures between $0^oC$ and $70^oC$.

The board is designed to handle load and battery currents up to a maximum of 10 A. At 12 V, this corresponds to the board capable of handling 120 W loads. Note that the power converter and tracking module is currently designed for 60 W solar panels. However, a simple inductor replacement will allow the board to handle panels of up to 120 W.

## References

[1] D.G. Vutetakis and H. Wu. The effect of charge rate and depth of discharge on the cycle life of sealed lead-acid aircraft batteries. In *IEEE 35th International Power Sources Symposium*, Cherry Hill, NJ, USA, Jun 1992.