WHITE PAPER

USE THE T80HV CHARGE CONTROLLER WITH 5 to 6kW of PV INPUT POWER

April 2017 John Pfeifer Rev 3

The question has been asked: What is the maximum size PV Array for the T80HV?
The short answer is over 5kW. The complete answer is complex and is the subject of this paper.

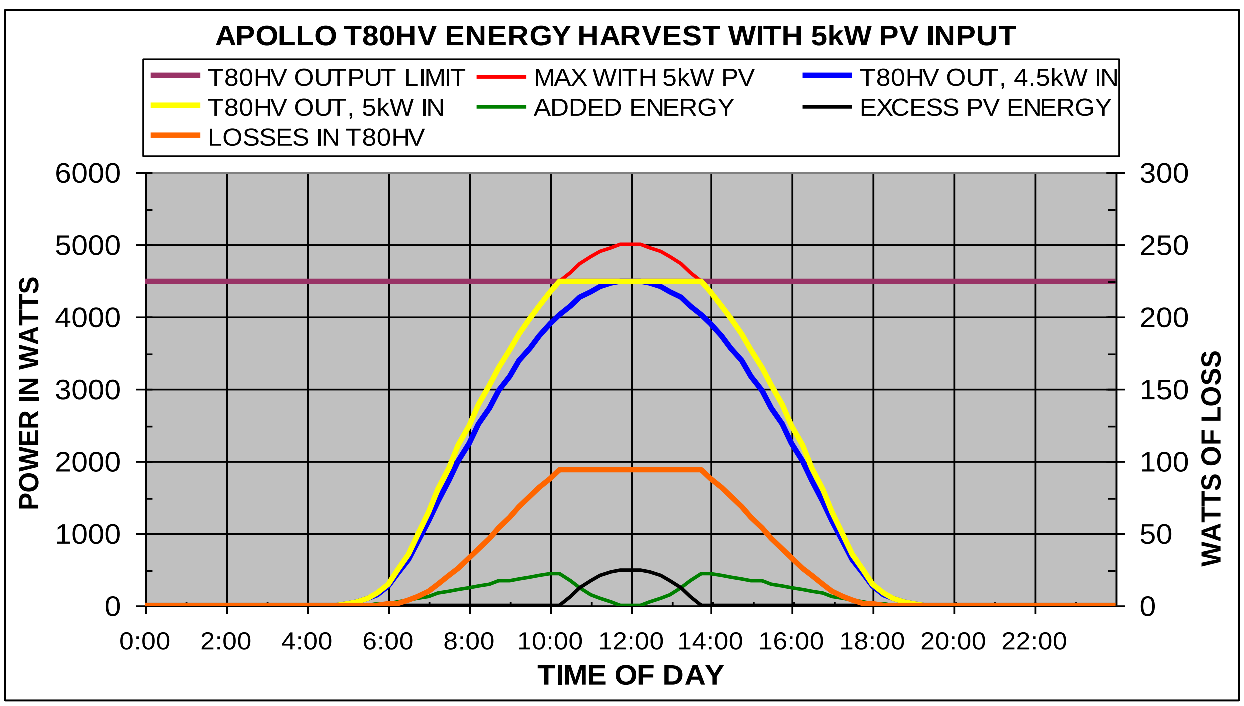
ENERGY HARVEST DURING THE DAY:

The graph below shows the Energy Harvests from a T80HV over 24 hours. The numbers assume 1000w/m^2 insulation, perfectly matched PV modules and zero loss in the wires from the PV array. And, they assume that it is a CLEAR DAY, ALL DAY. On a cloudy day, an "oversized" PV array will deliver more useful power and will not suffer as much around noon as the clear day examples.

In these examples we are charging a 48 volt battery with an Absorb voltage set point at 56.25v. The BLUE curve is the output of a 4.5Kw PV array. 4500 watts / 56.25v = 80.0 Amps which is the maximum that the T80HV will deliver to the battery. The VIOLET flat line at 4500 watts makes this limit clear. Some would say that 4.5Kw might be the maximum PV array for a T80HV.

RESULTS WHEN USING 5kW OF PV ARRAY:

The RED curve shows what 5kW of PV would look like without the 80 Amp output limit imposed by the T80HV. The YELLOW curve takes the 80A limit into consideration which produces the flat top at 4500 watts between 10:00 and 14:00 hours.



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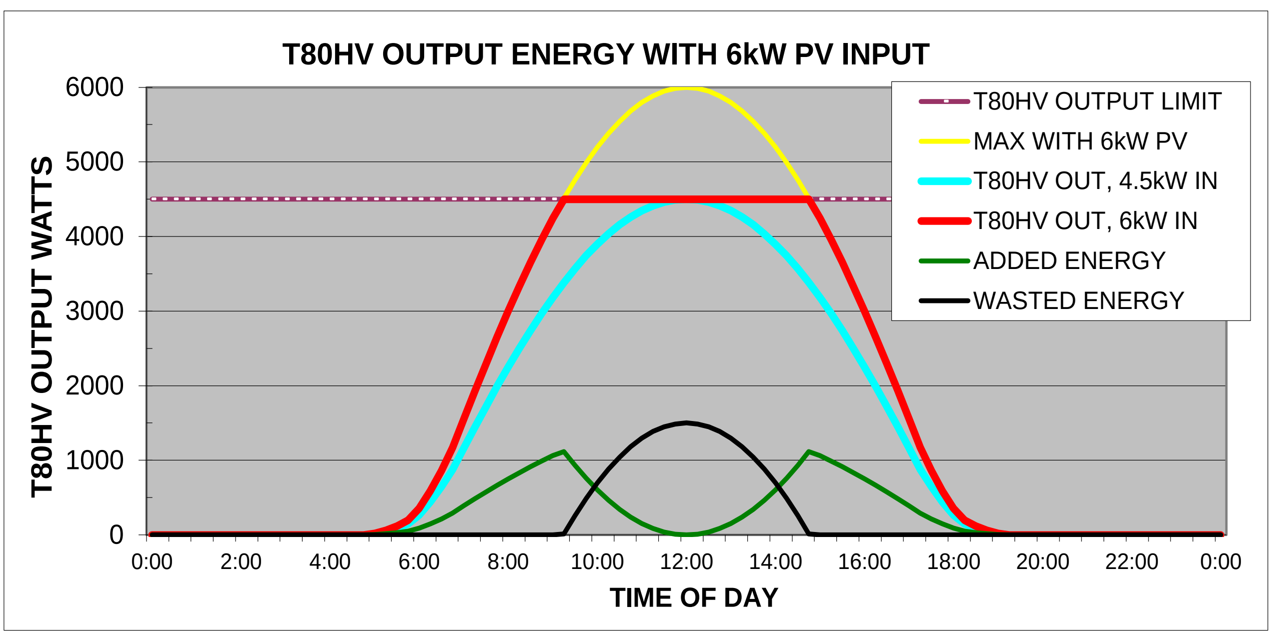
The point is that the T80HV does harvest a considerable amount of useable energy from a 5kW array before and after the noon peak which is represented by the area under the curves between the yellow and blue curves. For clarity, the GREEN curve shows the amount of added energy and the BLACK curve is the amount of excess energy from a 5kW array which cannot be used because of the 80 Amp output limit.

The results are that on a clear day, with clean new PV modules, the T80HV harvests 7.8% more kWh from the 5kW PV array than from a 4.5kW array. However, the 5kW array is 11.1% larger (and probably 11.1% more expensive), than the 4.5kW array so the benefit is not 100% because of the energy which can not be used around noon. If the sky is cloudy during the 4 hours around noon, the peak will not exceed the 80Amp limit, so the results of the 5kW array produce a large increase in output.

RESULTS WHEN USING 6kW OF PV ARRAY:

The RED curve shows what 6kW of PV would look like without the 80 Amp output limit imposed by the T80HV. The YELLOW curve takes the 80A limit into consideration which produces the flat top at 4500 watts between 9:00 and 15:00 hours. The point is that the T80HV does harvest a considerable amount of useable energy from a 6kW array before and after the noon peak which is represented by the area under the curves between the yellow and blue curves. For clarity, the GREEN curve shows the amount of added energy and the BLACK curve is the amount of excess energy from a 6kW array which cannot be used because of the 80 Amp output limit.

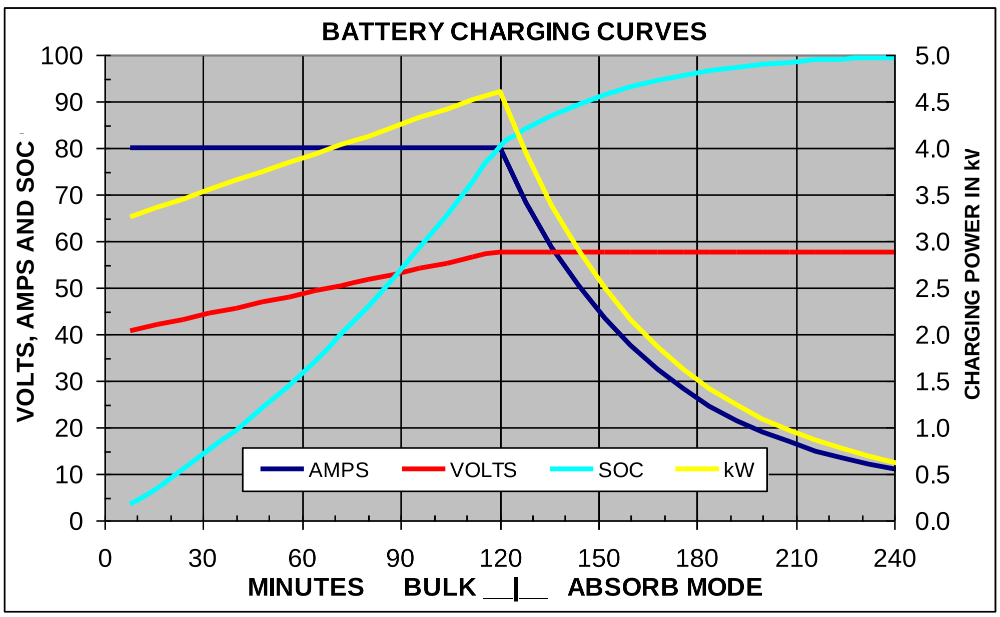


The T80HV harvests 17.6% more kWh from the 6kW PV array than from a 4.5kW array. However, the 6kW array is 33.3% larger (and probably 33.3% more expensive), than the 4.5kW array so the benefit is not obvious at first pass because of the energy which cannot be used around noon, on a clear day.

The results are that on a clear day, with clean new PV modules, the T80HV harvests 17.6% more kWh from the 6kW PV array than from a 4.5kW array. However, the 6kW array is 33.3% larger (and probably 33.3% more expensive), than the 4.5kW array so the benefit is may not perfect because of the energy which cannot be used around noon. However, if the sky is cloudy during the 6 hours around noon, the peak will not exceed the 80Amp limit, so the results of the 6kW array will produce a large increase in output.

BATTERY CHARGING CURVES:

The T80HV is a Battery Charge Controller so it is important to examine the battery charging curves as shown in the graph below. The first stage is Bulk charge which is a Constant Current mode. The current is shown in DARK BLUE at 80 Amp going into the battery from the T80HV.



During the Bulk or constant current charging stage, the battery Voltage (shown in RED) rises. The Charge Controller measures the battery voltage and at about 57 volts (56.25v in this example) it changes to a Constant Voltage charger. This Absorb Voltage Set point is shown on the graph at 120 minutes. It is settable for different cell chemistries or manufacturers specs and is then the battery temperature adds a compensation factor. In the Absorb mode (after 120 minutes in the graph), the current decreases because the battery can not take any more energy.

Note the YELLOW Power curve in the graph above which is in kW using the right hand axis. It is important to understand that as the voltage increases during the Bulk mode, the power increases as well, but then the current and power both sharply decrease during the Absorb mode.

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The LIGHT BLUE curve is the State of Charge (SOC) representing the amount of energy stored in the battery. At the end of the Bulk stage, a battery is typically 80% full. The Absorb stage is designed to fill the battery with the top 20% and is usually terminated by a timer.

It would be ideal if the power source, in this case solar, were to match the amount of power which can be used by the battery during the charging period (in YELLOW). The challenge is to size the PV Array and the Battery to work with the load and to approach perfection so the battery completes the Bulk charge stage during the solar peak in mid-day. A broader PV power peak around mid-day makes it easier to line up the battery power curve with the PV Array output power.

REAL-WORLD CONDITIONS:

The graphs and calculations so far were simplified for illustration by removing the losses that exist in the real world. The following real-world conditions must be considered so we do not mislead ourselves. When determining the amount of power that the T80HV will see at the output from a PV array rated at 5 to 6kW (peak power), one must consider the following factors. What you thought was a 5 or 6kW PV array may actually be producing much less power, so it makes sense to oversize the array.

1. The power provided by any PV module is directly proportional to the amount of insolation or the irradiance. The module specs are based on 1000 watts per square meter of irradiance. There is no typical amount of irradiance since it goes from zero to over 1000 w/m^2 and back to zero every day.

2. The PV modules decrease in output over time. Every manufacturer has a different specification, and none of them have been around long enough to verify their results after 20 years, but they claim 10% loss at 10 years and 20% loss at 25 years.

3. The output power of any PV Module is rated at a specific temperature (usually 25C). As the temperature increases, the output power drops considerably. Depending on the manufacturer and the technology, the decrease in power with an increase in temperature is typically 0.44% per degree C above 25C. Therefore, an array at 45C will be 20 degrees hotter which will result in 20 times 0.44% which is an 8.8% decrease in energy output.

4. The PV array for the T80HV Charge Controller is composed of 12 to 18 individual PV modules wired in a series parallel configuration. If the series string modules do not produce exactly the same current, the string current will be limited by the weakest module. Likewise, the parallel strings will be limited in voltage because strings with different voltages will fight each other. Some industry experts suggest that the imbalance in PV modules can result in up to 10% of decrease from the specified PV array power.

5. Dirt, sand and other pollutants on the surface of the PV modules simply reduce the amount of insolation getting to the silicon. This number can vary widely, but we can guess at 5% for degradation due to soiling.

6. The installers are directed to use wires that are heavy gauge such that the total resistance is low enough to make sure wiring losses do not exceed 2%.

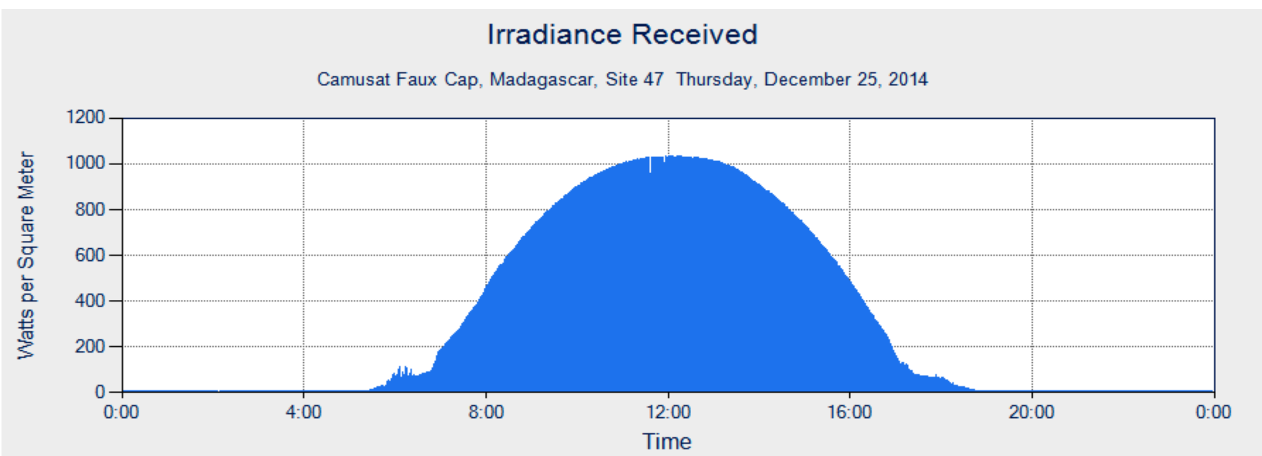
7. The Charge Controller is the last element in this series of possible losses. When charging a 48 volt battery with a properly designed PV array, the T80HV will be 98% to 99% efficient. Therefore the losses are 2% worst case.

The total of items 2 – 7 is 37.8%! That is the worst case in terms of the greatest degradation of the power output on a hot day at noon after 10 years. However, in this paper, we are concerned with the maximum amount of power which will be seen at the Charge Controllers. In this case, we have to assume the use of clean, new PV modules which are perfectly matched and mounted in perfect sunshine in 25C ambient temperature so all those losses add up to zero. The wiring losses can be cut in half to 1% by using short heavy gauge wire. So the output of the T80HV can be just 3% lower than the specified power. Note that the other 35% of losses are still real and will affect every installation to some degree. The bottom line is that it is wise to use the largest PV array that the charge controllers can tolerate under ideal conditions since the output will fall off with dirt, time and the other factors. In this case, we recommend 4500 to 6000 watts peak.

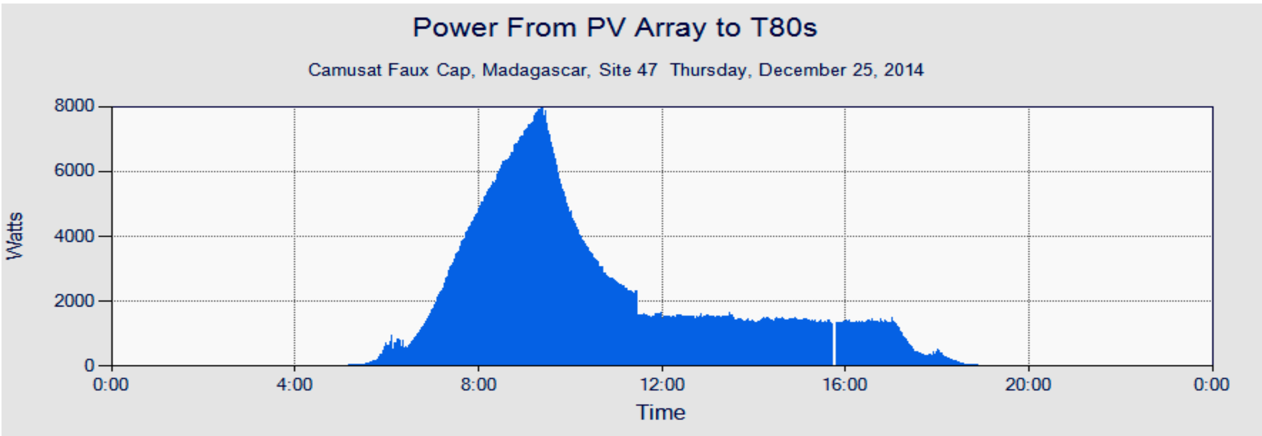
RESULTS IN ACTUAL FIELD OPERATION:

The ideal system sizing described above is not just a theory. Apollo Solar is the leader in pure power energy systems for remote telecom installations where reliability and cost effectiveness are both critical. We fine-tune our system designs and attempt to achieve the ideal match between the PV Array and the Battery Charging power curves.

Our energy systems which are based on the T80HV MPPT Charge Controllers include Remote Monitoring software which allows us to see how close the systems are to the ideal match. The data is sent to our server every minute so the resolution is superb. The screen shots below show 2 of the many graphs available. The graph immediately below is the output of the irradiance sensor at the site which shows the expected results with the peak around noon. This was a very clear day south of the equator and the peak is over 1000 watts per square meter.



At the same site, on the same day, the curve below shows the Power from the PV Array into the T80HVs which peaks at about 9:45 AM on this unusually clear day. At that instant, the battery switched to the Absorb mode and the power required by the battery drops off exactly as predicted by the battery charging curves. On days with less solar input, the battery simply takes longer to reach the Absorb set point. The Battery Absorb charge mode times out at 11:45 and the power harvested by the T80HVs for the balance of the solar day is used by the load.



<u>Having this feedback from the sites in the field allows Apollo Solar to close the loop with our system designs and to verify the operation of every part of the energy equipment at the sites.</u>

CONCLUSIONS:

From the graph of the Power which can be actually used by the Battery and the Load in the graph immediately above, we can see that the using an oversized PV array at up to 6kW would not suffer any drawbacks since the battery cannot use any additional power after 9:45 AM.

In addition, since there are many factors which reduce the actual output power of any PV Array, it makes good sense to oversize the array.