APOLLO SOLAR

WHITE PAPER

HYBRID SOLAR / DIESEL GENERATOR BATTERY BASED REMOTE ENERGY SYSTEM

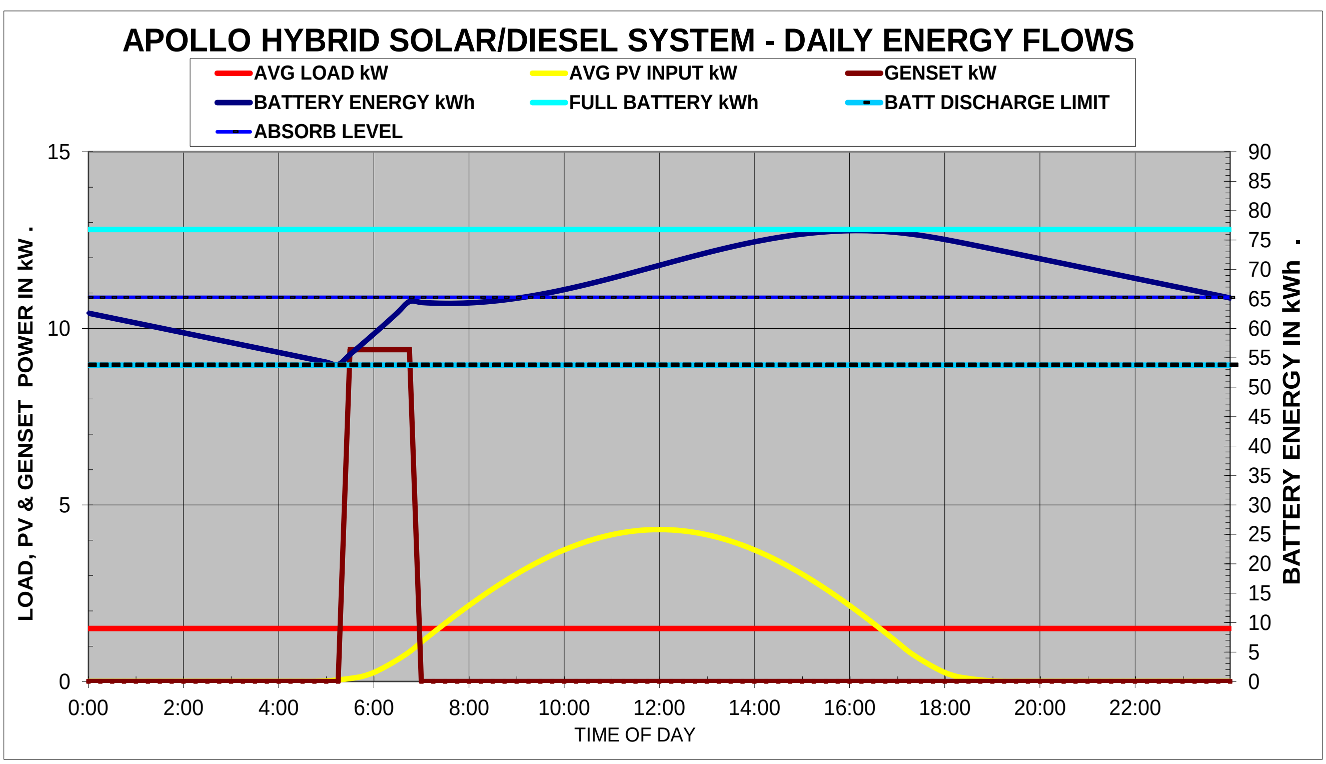
January 2017 John Pfeifer

The question has been asked: How does the Apollo Hybrid Energy System use both Solar and Diesel with optimum results? This paper provides the answer.

ENERGY FLOW DURING A TYPICAL THE DAY:

The graph below shows the Energy Flow over a 24 hour day. The X axis is the time of day with solar noon in the center. The Right Y axis is Power of the Load, the PV input and the Diesel Generator (DG) input in kW. The Left Y axis is the Energy of the Battery in kWh. The example in the graph below is a 1.5kW constant Load, 4kW of PV with a 10kW Diesel Generator as backup.

The Dark Blue Curve on the graph below is the critical Battery State of Charge. The Red line is the Load and the Yellow curve is the PV energy input. The point of this graph is to show when the DG is turned on to charge the battery. In this example, the Brown Pulse shows the DG turned on at 5:15AM and turned off at 6:45AM. The Solar PV input is considered free energy but is used carefully to charge the battery. Our system is designed to meet these essential rules: 1) The DG must be started to prevent the Battery from becoming deeply discharged, 2) The DG should be Stopped as soon as possible to minimize run time and fuel consumption.



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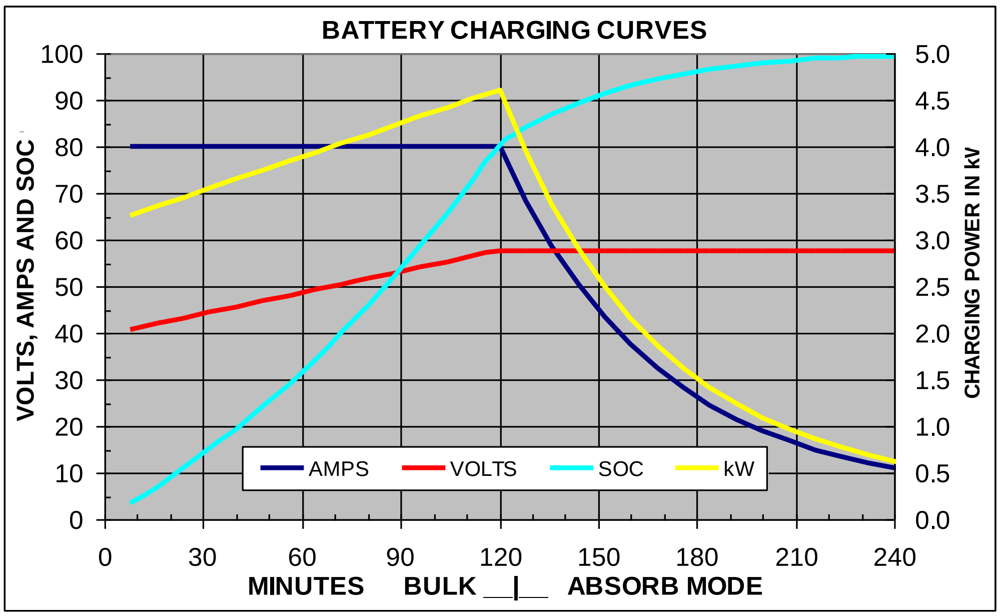
Referring again to the graph on the front page, the Light Blue horizontal line is the maximum battery capacity. The Dotted Blue line is the maximum Depth of Discharge. In this example, it is set at 30% below the full capacity. Between these two lines we show the Absorb Voltage Level. Below this line, the battery charger is in the Constant Current mode. When the battery energy, or State of Charge, reaches this point, the battery is about 80% full. Above this line, the charger is in the Constant Voltage mode.

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.



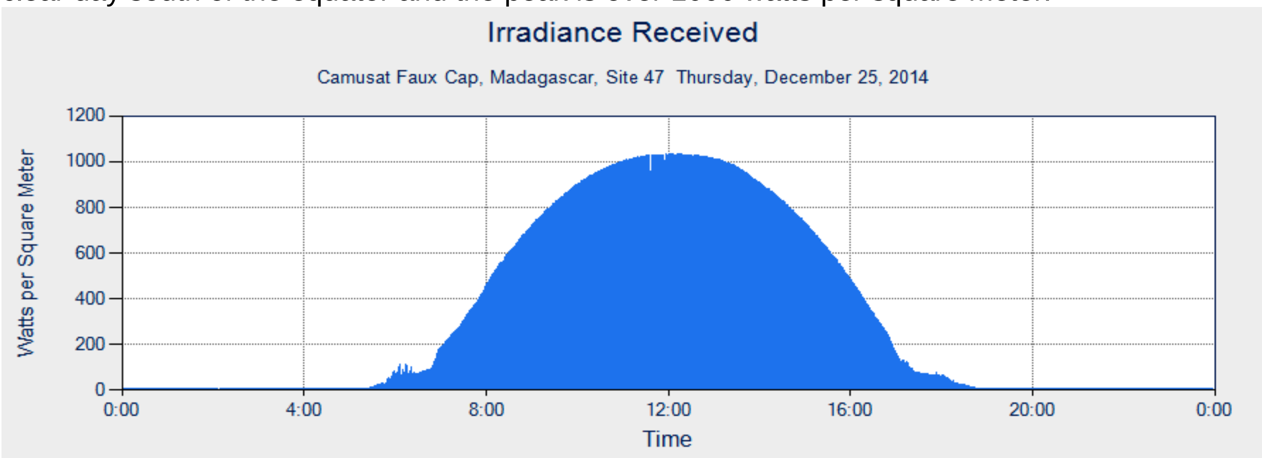
During the Bulk or constant current charging stage, the battery Voltage (shown in RED) rises. The Charge Controller measures the battery voltage and at about 57 volts (56.25v in this example) it changes to a Constant Voltage charger. This Absorb Voltage Set point is shown on the graph at 120 minutes. It is settable for different cell chemistries or manufacturers specs and 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. 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.

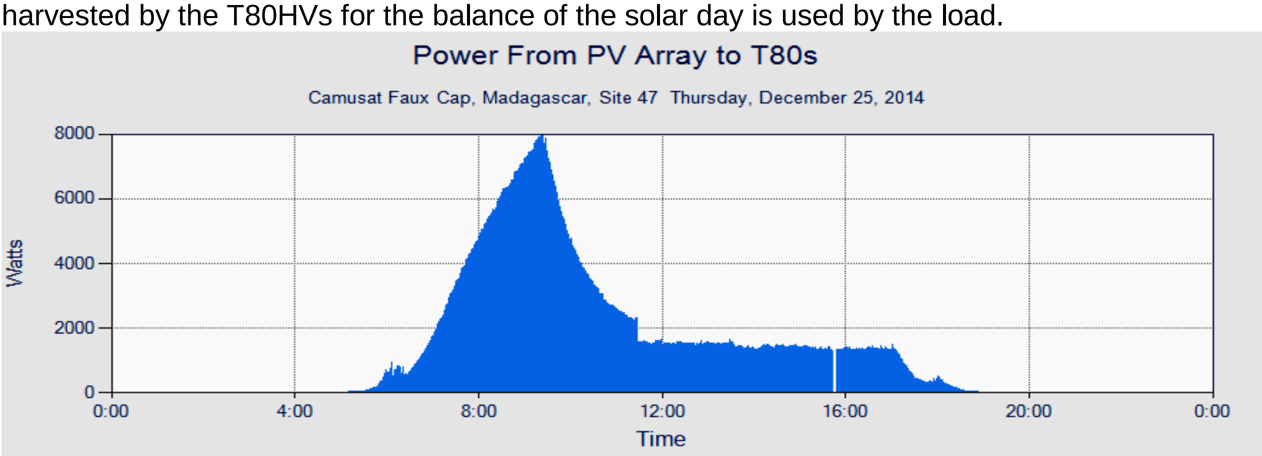
RESULTS IN ACTUAL FIELD CONDITIONS:

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 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 each system is 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 reports available. The curve 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>