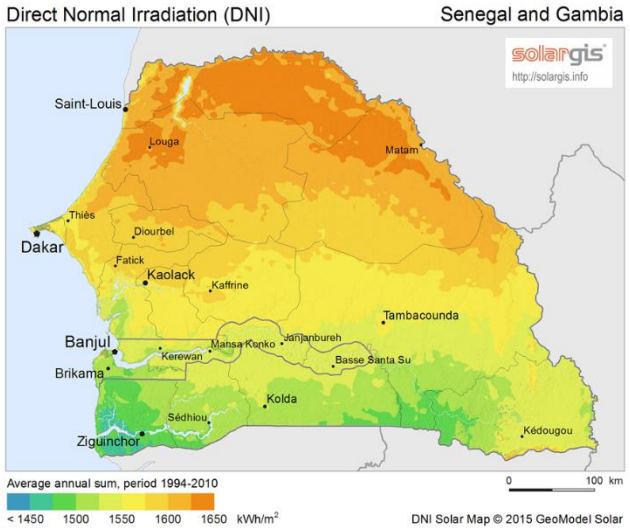
System Design Basics - Remote Energy Systems for Telecom Towers



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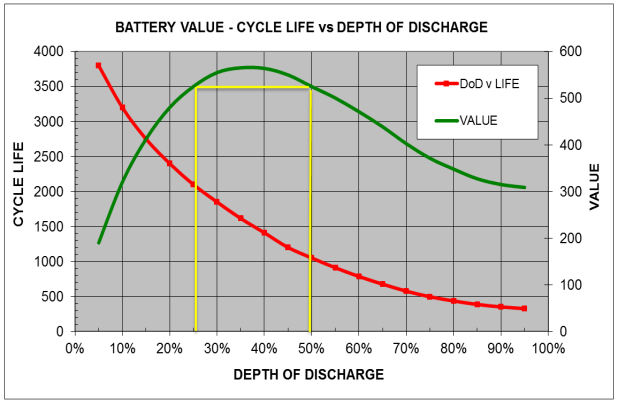

Providing Energy in Remote Locations – Page 1

The costs of providing remote energy have changed over the past decade

- **RELIABLE CONTINUOUS ENERGY** – Every mobile telephone tower must have continuous energy 24 hours per day, every day. Going "dark" has costly penalties.
- **GRID POWER** – If the Utility Grid is reliable and close by, simply plug in and use it.
- **BEYOND THE GRID** – Mobile phone service has expanded beyond the electric grid.
- **STEP 1 – Install Generators** – Today there are 640,000 BTS towers running on diesel generators. Good start, but now the cost of running these generators must be reduced.
- **STEP 2 – Add Deep Cycle Batteries** – Generators could be turned off for a number of hours each day and then run at a more efficient power level. When diesel fuel costs were over $1.50 per liter, this made sense. But cycling the batteries many times per day burned them out in less than a year. The cost of replacing the batteries is no longer affordable.
- **STEP 3 – Add some Solar** – The cost of PV modules is now low enough to make Solar a serious choice. Tower owners have experimented by adding small solar arrays and use the free energy during the day, but the cost of keeping the generators running remains.
- **The NEXT STEP – PURE SOLAR**

Providing Energy in Remote Locations – Page 2

The costs of providing remote energy have changed over the past decade

- **The NEXT STEP – PURE SOLAR** – Apollo Solar has proven that Solar is now the most reliable and most cost effective way to provide energy for BTS towers in remote locations.
- **>900 Towers Running with 100% Up Time** – Since reliability is a critical factor, this fact is often the closing argument.
- **A large PV Array now costs less than one generator.** The generator must be replaced every 2 years, the PV modules are guaranteed for 25 years and they don't use any fuel.
- **Why is Solar so reliable?** No moving parts to wear out, no maintenance, no fuel.
- **Why is Solar so cost effective now?** The cost of the PV modules has come down from about $6.00/watt in 2006 to $0.60/watt in 2016!! (Wow). And the amount of solar energy available in developing nations (where there is no grid) is high at over 5kWh/m^2/day.
- **What is a Pure Solar system?** Just a large PV array and a large battery. Our electronic cabinet does everything to manage the solar, battery and load and reports over the web.
- **What is a Hybrid Solar/DG System?** When the site does not have enough area for the PV Array to provide energy for 3 days of dark weather, we add a small backup generator.

The Old Way of Thinking: 1

STEP 1
When Utility Grid Power is not available, AC Generators are simply installed on site.

Two Generators are required for reliable continuous energy.

Rectifiers turn the AC into 48V DC

The Tower BTS needs 48V DC at typically 2kW.

The AC Generators are oversized and run at <20% of full power which is very inefficient.

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The Old Way of Thinking: 2

Step 2 - To reduce fuel consumption, Deep Cycle Batteries were added. The Generators could be turned off for many hours saving 30% in fuel. <u>But the batteries don't last long when cycled many times each day.</u>

Two Generators are still required for reliable continuous energy.

The AC Generators are oversized, but run at 100% of capacity so efficiency is improved.

Rectifiers turn the AC into 48V DC

Deep Cycle Batteries provide continuous DC power.

The Tower BTS needs 48V DC at typically 2kW.

<u>The problem is that the batteries are not perfect. They lose 20% of the energy round trip, so the cost of running the generator is 20% higher.</u>

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The Old Way of Thinking: 3

Step 3
A small amount of Solar was added to reduce the genset run time further and to look "green".

Two Generators are still required for reliable continuous energy.

The AC Generators are oversized, but run at 100% of capacity so efficiency is improved.

Rectifiers turn the AC into 48V DC

Charge Controllers

Deep Cycle Batteries provide continuous DC power.

The Tower BTS needs 48V DC at typically 2kW.

<u>But, this site still depends on the Diesel Generator for most of the power.</u>

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The NEW Way of Thinking

Step1
Start with enough Solar and Battery to keep the Tower running for 3 days.

Charge Controllers, Switchgear and Remote Monitoring

The Tower BTS needs 48V DC at typically 2kW.

Step 2 – If the space limits the PV Array, add a small (8kW) DC Generator for back up to fill in the difference.

Deep Cycle Batteries provide continuous DC power.

The losses in the battery are not critical because the Solar energy is essentially free.

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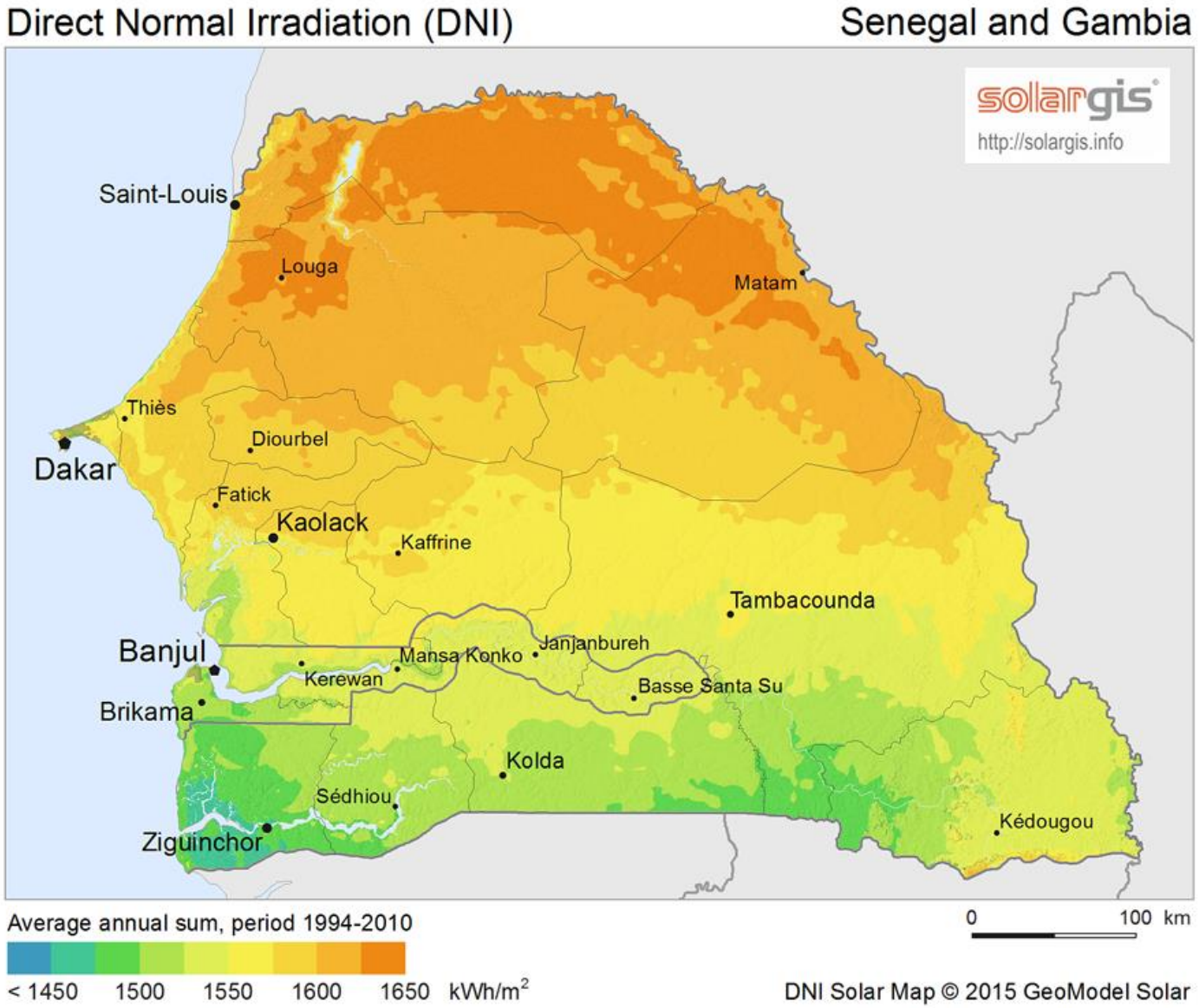
Summary of System Design - Irradiation

The Map at the right is shown in Annual averages. We use the energy per day which is simply the annual average divided by 365.

So Louga will have 1650/365 or 4.52 kWh/m^2/day average.

For Pure Solar systems, we must use the Minimum instead of the Average. Tables are available showing the min every month.



Summary of System Design

Pure Solar Systems – No diesel generator or grid

1. The BTS is a constant Load supplied by the Battery 24/7.
2. The Battery must be recharged early the next day.
3. The PV Array is sized to provide all the energy to recharge the battery in one day while also powering the load.
4. Rule of thumb: PV Array to Load Ratio (ALR) of about 10:1. So a 1kW load will require about 10kW of PV Array. 9:1 ALR is also used.
5. Clouds will limit the Solar on some days, so the battery is oversized. Providing 3 days of Autonomy allows the system to run for 3 days with zero solar without damaging the batteries. Some locations require more autonomy.
6. Rule of thumb: The battery in kWh (at C100) will be about 130 times larger than the load in kW. So a site with 2kW Load will need a 260kWh battery. That is 5,000 Amp-Hours using 52 charging volts.

Pure Solar Examples

The actual sizing calculations done by Solene shown at the right show the results from calculations for 29 sites in West Africa.

The average ALR is 9.65 to 1.

The average Battery to Load ratio is 129 to 1.

We have found that these factors make reliable Pure Solar sites and are typical of the 900 sites using Apollo Solar equipment in Africa over the past 4 years.

If the average Insolation is low, the ALR must be increased. If the climate has monsoon storms with many days of darkness, the battery size must be increased.

SITE REFERENCE NAME	LOAD IN WATTS	ACTUAL PV ARRAY IN WATTS(p)	ARRAY TO LOAD RATIO	ACTUAL BATTERY CAPACITY Ah @ C100	BATTERY CAPACITY IN kWh	BATTERY TO LOAD RATIO
SUSANA	**1163**	11,340	9.75	3210	164	141
ONDAME	**2316**	22,680	9.79	5460	278	120
VARELA	**1129**	11,340	10.04	2730	139	123
PITCHE	**1901**	17,955	9.45	4560	233	122
CÓ	**1100**	10,395	9.45	4110	210	191
BINAR	**2606**	25,515	9.79	6510	332	127
BAFATA 2	**2304**	22,680	9.84	5460	278	121
PRABIS	**2345**	22,680	9.67	5460	278	119
GABU EMBALO CUNDA	**2519**	24,570	9.75	6510	332	132
DEMBA CALI ORANGE	**1518**	15,120	9.96	3660	187	123
CATEL ORANGE	**1546**	15,120	9.78	3660	187	121
BAMBADINCA PRACA	**2387**	22,680	9.50	6510	332	139
CONTUBOEL	**2243**	21,735	9.69	5460	278	124
GALOMARO	**1639**	16,065	9.80	4110	210	128
XITOLE	**1699**	16,065	9.46	4110	210	123
CUTIA	**1550**	15,120	9.65	4110	210	135
SALTINHO	**1551**	16,065	9.39	4110	210	135
CUTIA (2)	**1567**	15,120	9.65	4110	210	134
SALTINHO (2)	**1710**	16,065	9.39	4110	210	123
PONTA GARDETE	**1824**	17,955	9.84	4560	233	128
ZONA 7	**2665**	25,515	9.57	6510	332	125
GABU 2017	**2665**	25,515	9.57	6510	332	125
BAFATA 2017	**2665**	25,515	9.57	6510	332	125
BUBA PRACA	**3507**	34,020	9.70	8700	444	127
CUNTUM2	**2665**	25,515	9.57	6510	332	125
CANCHUNGO 2017	**2665**	25,515	9.57	6510	332	125
QUELELE	**2665**	25,515	9.57	6510	332	125
ANTULA 3	**2665**	25,515	9.57	6510	332	125
BISSORA SECTOR 2017	**1300**	12,285	9.45	3210	164	126
	LOAD	**PV WATTS**	**ALR**	**Bat Ah**	**Bat kWh**	**Bat:Load**
AVERAGES:	**2072**	**20,041**	**9.65**	**5172**	**264**	**129**

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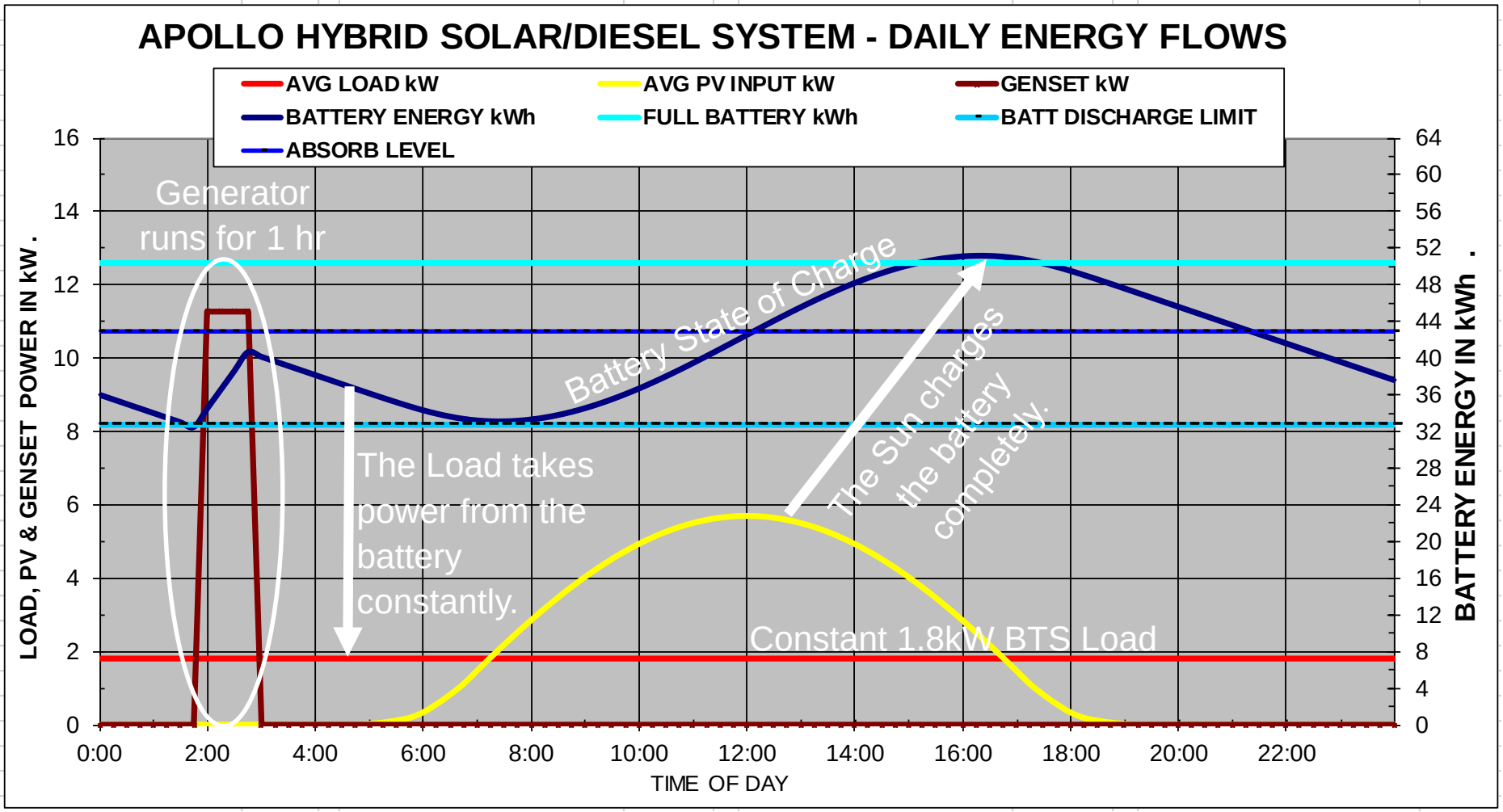
Summary of System Design

Solar / DG Hybrid Systems –Add backup generator

1. The difference from the Pure Solar system is that the 3 days of autonomy can be reduced to 1 day or less.
2. Cutting the size of the Battery by a factor of 3 cuts the cost greatly.
3. This reduces the initial Capital Expense (CAPEX), with an increase of the Operating Cost (OPEX) which is the diesel fuel and all other generator maintenance costs.
4. The optimum balance of PV Array and Battery size to Generator Run Time and Fuel Consumption is an important set of calculations.
5. The Apollo equipment works with the entire spectrum from Pure Solar to total DG.
6. Many sites have a limited amount of land and that becomes the limit on the size of the PV Array.
7. Some customers will request that the sites be 70% Solar and only 30% Diesel. We use a software simulator to achieve these targets.

How the Apollo Hybrid Solar/DG System works

This chart shows when the battery is charged. The BTS load is always on.



Apollo Solar

Simulation of Hybrid Solar/DG System

APOLLO SOLAR - HYBRID DG SIMULATOR - REV 33 - Copyright 2015 | 0 | CONFIDENTIAL

1.8 kW | MODEL: B | AGM Lead Acid Battery

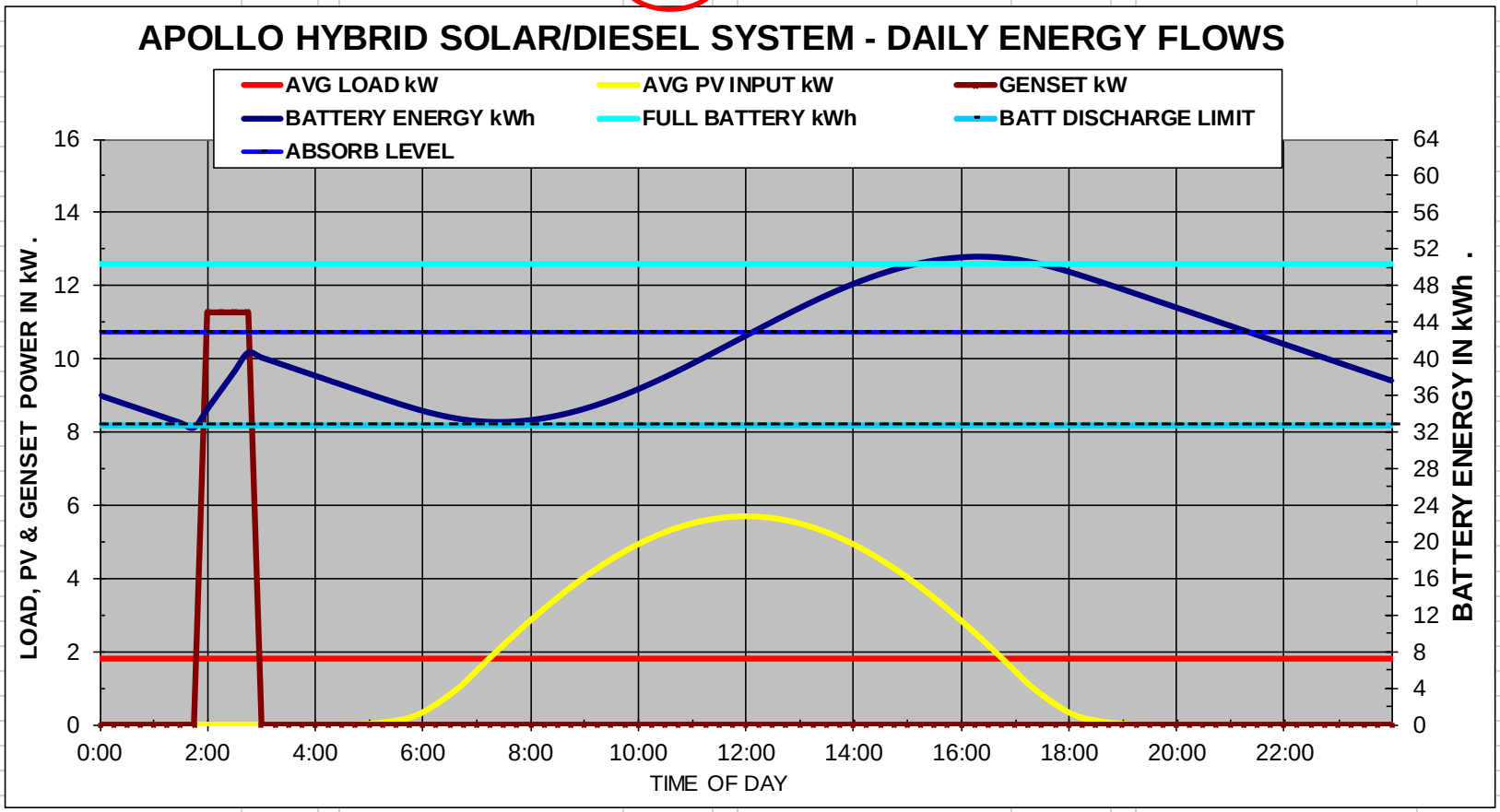
INDIA | CELLA TECH

GIVENS	
TOWER LOAD IN kW	1.8
ANNUAL AVG INSOLUTION	5.56
GENSET SIZE IN kW	12.0
GENSET RUN POINT	100%
DG BATT CHARGE AMPS	182
ENERGY REQ IN kWh/DAY	56.5

SOLAR ARRAY RESULTS	
PV ARRAY IN kW	7.8
SQ METERS FOR PV ARRAY	45.3
NUM OF T80HV CHG CTLRS	2
PEAK PV CHARGE AMPS	69.3
PV ENERGY in kWh/DAY	43.8
% OF ENERGY FROM SOLAR	77.6%

BATTERY RESULTS	
MAX ALLOWABLE DoD	35%
CAPACITY in Ah at C10	1050
CAPACITY REQUIRED IN kWh	30
MAX BATT CHARGE AMPS	336
DEEP DISCHARGES / YEAR	730
BATTERY LIFE IN YEARS	2.7

GENSET RESULTS	
GENSET RUN TIME IN hr	1.00
RUN TIME AS % OF DAY	4.2%
FUEL USAGE IN LITERS/DAY	4.06
FUEL USAGE IN LITERS/MO	124
TOTAL DG ENERGY kWh/DAY	12.0
% OF ENERGY FROM DG	21.2%



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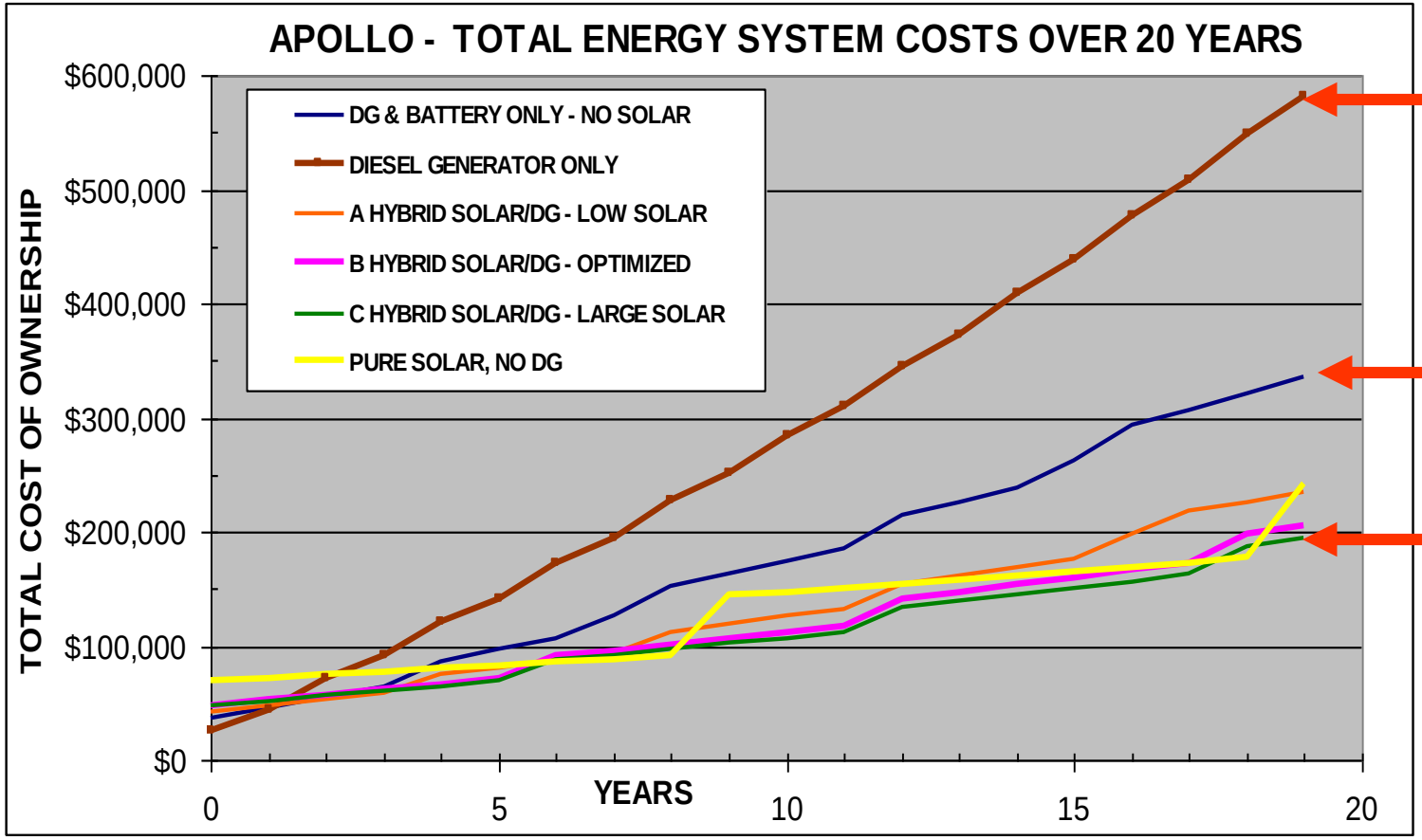
Total Cost of Ownership



COSTS OF THE EXISTING DIESEL GENSET

COSTS OF GENSET WITH DEEP CYCLE BATTERIES

COSTS OF THE APOLLO PURE SOLAR AND HYBRID SOLUTIONS

The TCO chart shows a real 1kW load system. The costs for each system depend on local parameters including the cost of diesel fuel and the solar irradiance available.

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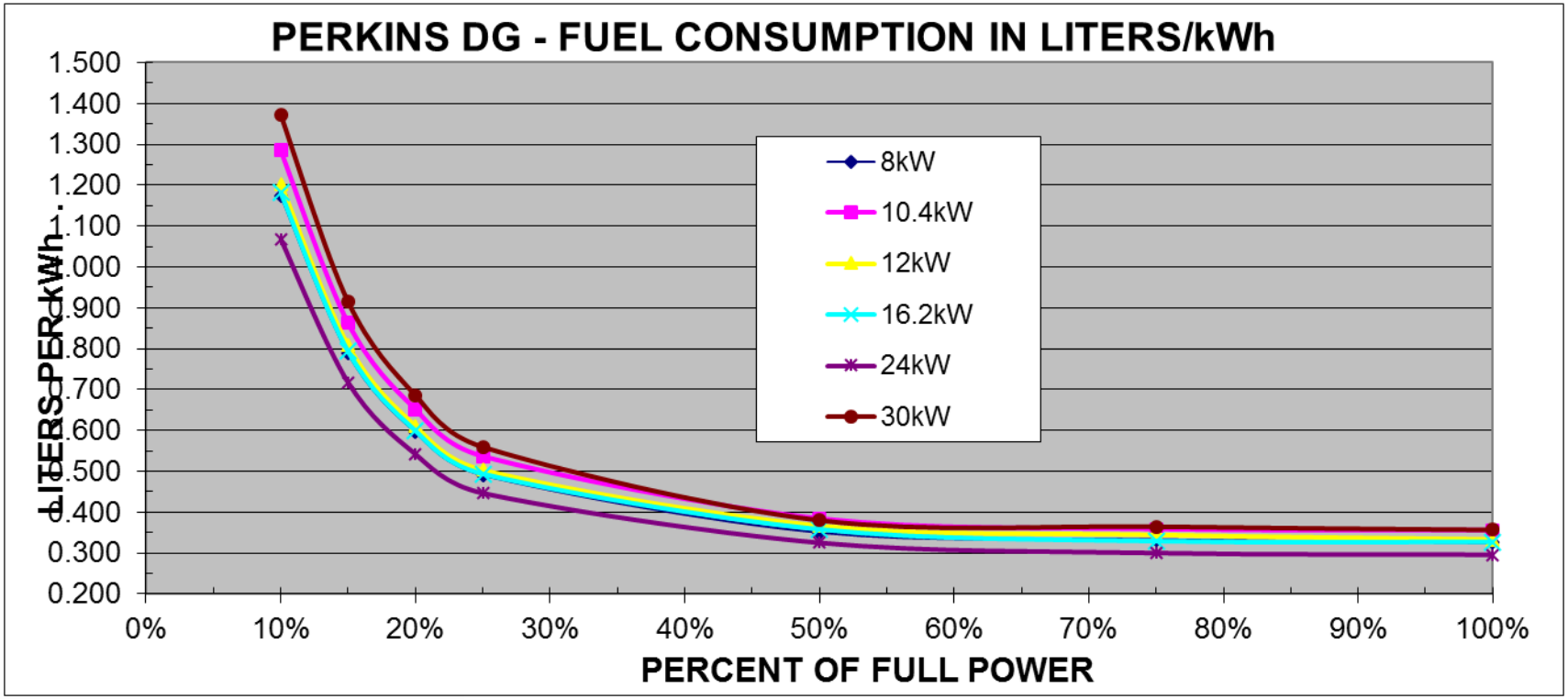
The Efficiency Curve of Diesel Generators

With Solar added, we run the generator at 3 to 4 times better efficiency than DG only.

- A typical site using diesel generators has 2 generators that are 12kW to 24kW each.
- The avg tower load is 2kW, so the generators are running at 8% to 17% of full power.
- From the chart below, we see that the fuel consumption at 10% of full power is about 1.2 Liters per kWh.
- We add solar and batteries and run the Generator at 100% full power so the fuel consumption is only 0.3 Liters per kWh – a full 4 times improvement.



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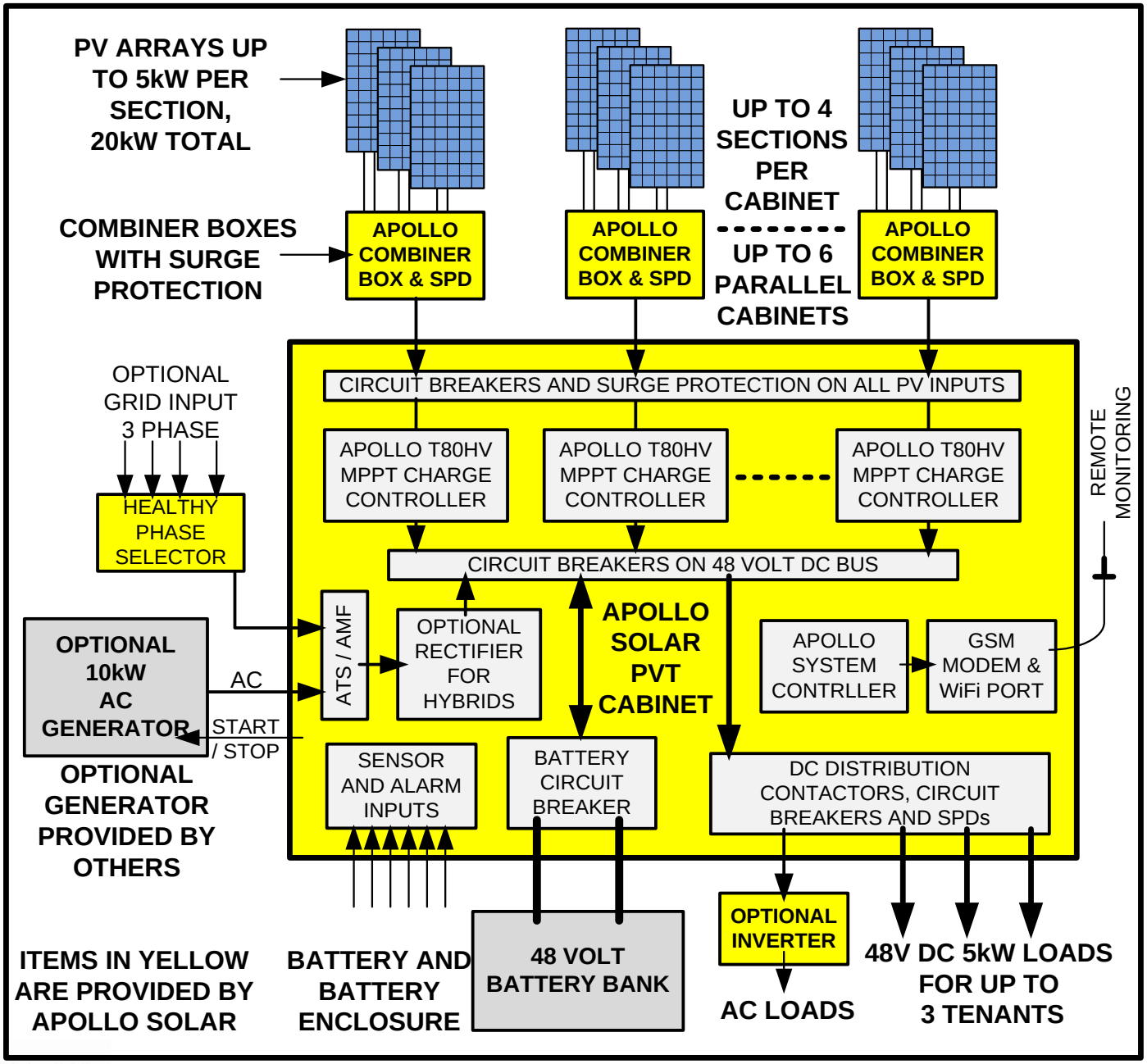
Apollo Solar Hybrid Power System Block Diagram

The Apollo system provides all the elements to provide reliable energy for the tower.

Options allow our system to provide all possible features cost effectively.

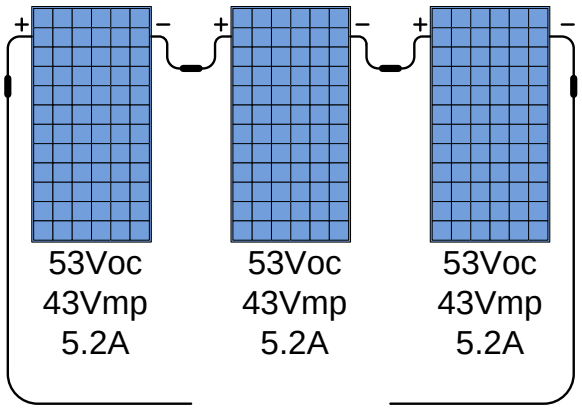
The input can be Solar, Generator, or Utility Grid.



Designing the PV Array

WIRING PV MODULES FOR THE BEST VOLTAGE

Using Sanyo HIT 225 watt modules



3 Modules in Series is 675 watts
159 volts open circuit,
129 volts at maximum power,
with 5.2 Amps at maximum power.

A run of 60 meters using 6mm^2 (200 ft of No 10) wire will have about 0.2 ohms of resistance which is 5.4 watts or 0.8% loss of power.

With the same modules wired in parallel with the same wire will have 48.7 watts or 7.2% loss of power.

PV Module Wiring

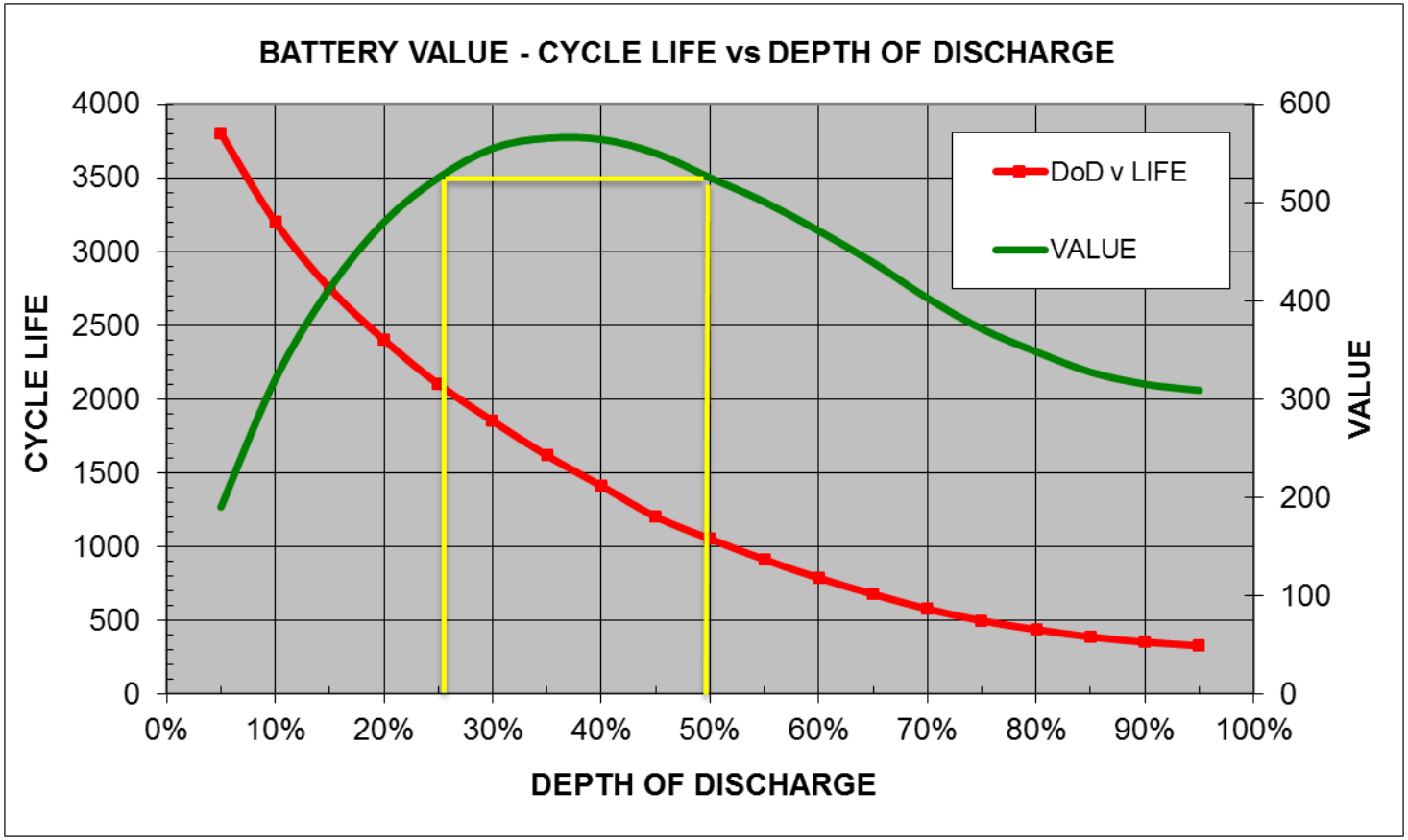
1. The rule of thumb is to use the highest voltage that the Charge Controller can take. Keeping the current low reduces the losses in the long runs of wire.
2. The Open Circuit Voltage of the modules at the coldest temperature the PV array will ever see is always the limiting factor.
3. <u>The Apollo Solar T80HV requires at least 16% greater voltage from the PV array than the maximum voltage needed to charge the battery.</u>
4. Typically this means that 3 PV modules will be wired in series in each string.

These are Battery Based Systems

- **COST** – The battery can often be 50% of the cost of the energy system. Proper sizing and selection of the battery type makes a big difference in the cost of your energy.
- **CAPACITY** – The price of the battery is based on its rated capacity. The Apollo Solar Charge Controllers make sure 100% of the rated capacity is used effectively. We measure the battery voltage at the battery terminals continuously for accurate charging. When the battery needs equalization, we provide that automatically.
- **LIFETIME** – If the battery is not charged properly, the lifetime will be reduced. The Apollo Solar Charge Controllers optimize the battery life. The voltage and temperature are monitored accurately and charging voltages are adjusted automatically.
- **SIZING** – We use a separate enclosure for the batteries so the size of battery bank can be optimized for each site.
- **EXPERIENCE AND FEEDBACK** – Apollo monitors the sites that are installed using our electronics. We have the feedback of the performance over years on hundreds of sites so we can be certain with battery or PV array sizing to optimize cost and performance.
- **CELL CHEMISTRY** – The Apollo Solar T80HV is designed to charge all available battery types including: AGM, GEL and Flooded Lead-Acid, Ni-Cad, Nickel-Iron and Lithium Ion including LiFePO4. As Lithium Ion batteries become more cost effective, we are ready to use them.

Battery Depth of Discharge for Optimum Value

1. A battery will provide more Charge-Discharge Cycles if the DoD is lower.
2. However, at <25% DoD, the size of the battery must be increased such that the initial cost can outweigh the advantage of longer cycle life.
3. At >50% DoD, the cycle life becomes shorter and the value is lost.



Batteries in Separate Enclosure

By providing a separate enclosure for the batteries, Apollo systems can be optimized for the conditions at each site.

Insolation, ambient temperature, size of PV array, cost of diesel fuel and size of the DG figure in the optimization of battery size.

Battery Facts

Over-sizing the Battery Never Hurts

1. The battery must be the Deep Cycle type, no exceptions.
2. Flooded, AGM and GEL all have pros and cons. If the end user is not going to maintain the water in the cells, then AGM or GEL will be a better choice.
3. The size of battery in Amp-Hours must include:
   Maximum Depth of Discharge 25% to 50%.
   Several days of running loads without charging.
   Safety margin of 20% to cover aging and cold temperature

1. Wiring battery cells in series up to 48 volts is normal.
2. Wiring batteries in parallel should be limited to 3 strings.
3. It is good practice to use series strings of large 2 volt cells.
4. The weight must be considered in transporting the battery.