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AN034
Battery hibridization in off-grid solar powered installations

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Application Note AN034

Battery hibridization in off-grid solar powered installations

Summary

Renewable energy is becoming a trend in the energy generation mix. Especially, when energy needs to be produced localized, photovoltaic installations are the most popular. Solar panels have also experienced a high reduction in cost and favourable regulation from the governments to ease and approve faster new installations.

In off-grid installations, where solar panels become the sole energy source, an energy buffer ,such as batteries, must be included to feed the loads in every situation. Due to the high intermittency of solar generation, the load, location, power and capacity installed must be properly sized to avoid any power failure.

Due to the low-cost and long run of lead-acid batteries in the industry , these chemistries have been widely used in the market so far. New lithium based battery chemistries have evolved in the last decade to compete in several markets with the lead-acid traditional batteries achieving improvements in energy density, cyclability and cost. These improvements have propelled the implementation of Lithium batteries in many markets related with mobility and small devices.

Due to the higher costs of lithium batteries, this application note covers the benefits of hybridizing lead-acid and lithium batteries in stationary solar powered installations.

Traditional Energy Storage System. Lead-Acid Batteries

In an off-grid installation powered only from solar panels, the batteries never reach a state of fully charged. Lead-acid batteries have three charging stages. In the first stage, bulk, the battery absorbs the most current. In the second stage, boost, the current is reduced while fixing the voltage and in the third stage, float, the voltage is fixed at a lower level.

In solar installations, the first stage of the charging process is completed as all the solar energy is absorbed but due to the reduction of current absorption in the second stage, most of the solar energy is lost. Additionally, lead-acid batteries would require up to 72 hours to fully charge and avoid degradation which is not achived because of the limit of hours of sunlight.

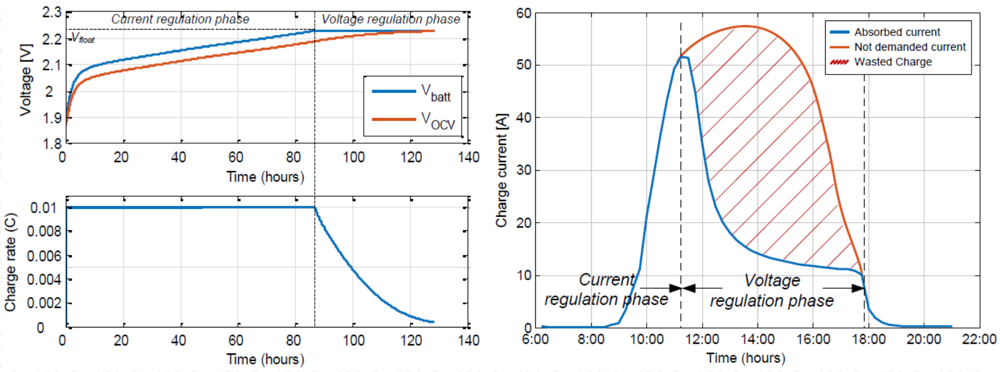

Fig. 1: Charging stages. Controlled charge vs charge from solar panels

In Fig. 1, the different charging stages and the internal voltage of the battery are introduced for a VRLA battery. On the left side, a complete theoretical charging process is depicted. On the right side, a gauss-bell-shaped solar profile is depicted in red with the maximum absorption of a lead-acid battery in blue. Most of the energy is lost.

As the solar generation is limited to the hours of sunlight, the battery cannot be charged completely and ends up stabilizing at a new state of charge. According to simulations and measurements taken, the new state of charge can be found between 60 and 80 % of the initial capacity of the battery. In Fig. 2, the reduction in the stabilization of state of charge over a period of 5 months is shown.

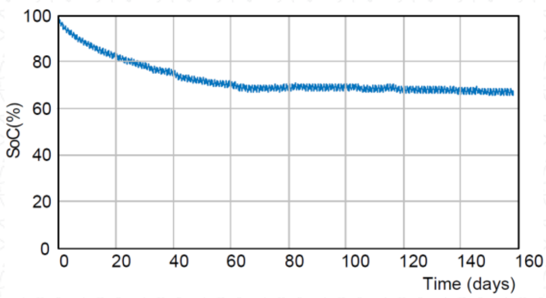

Fig. 2: Reduction in state of charge caused by limited solar charge

Optimized ESS: Lead-Acid + Lithium + DC/DC converter

To study the operation and benefits from a hybrid solution, VRLA batteries and LiFePO4 batteries, as depicted in Fig. 3, are considered. The "Support Storage System" includes the Lead-acid battery (biggest capacity) and the "Cyclic Storage System" includes the Lithium battery with a smaller capacity.

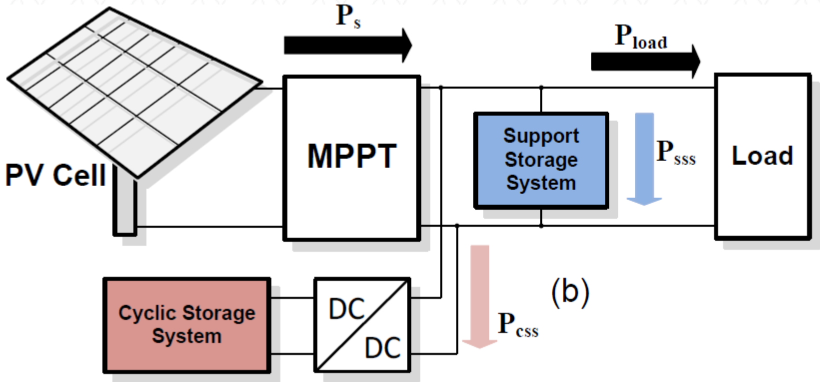

Fig. 3: General schematic: Battery hibridization in standalone isolated installation

With a hybrid configuration of batteries it is possible to increase the solar energy captured in the battery for the same total capacity in the system (e.g: 50 kWh of lead acid battery can be charged less from solar panels than a combination of 40 kWh of lead acid and 10 kWh of lithium batteries) .

This statement is shown in Fig. 4, where the state of charge of the lead-acid battery in a installation is depicted in yellow and the state of charge of a hybrid installation with lithium and lead-acid batteries is depicted in blue and orange. The graphs in Fig. 4, show that by including lithium in the installation with a specific control that optimizes the use, the lead-acid battery is much less used and the total usable energy capacity in the installation is increased by 25 % with the same theoretical capacity.

This result leads to the optimization in size and cost of high capacity applications.

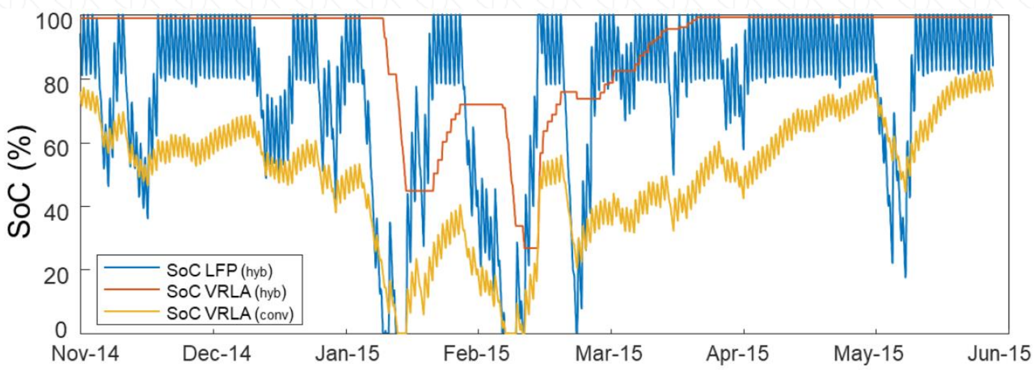

Fig. 4: Comparison in SoC level between (Yelow) pure lead-acid battery and (Blue&Orange) hybrid battery in off-grid installation

In existing or new installations it is especially important to consider the hybridization factor (1) as a relation between the energy/capacity in the lithium battery with the total amount in the system. Several studies have been published taking into account the autonomy required, the relation between generation and consumption (2), location, cost and resilience (3), LOLP(% of time when the battery cannot supply the load.)

$$\text{Hybridization factor}: \; F_{hy} = \frac{E_{LiFePO4}}{E_{total}} \qquad (1)$$

$$\text{Relation between generation/consumption}: \; GR = \frac{P_{pk_{solar\ panels}}[W]}{P_{consumption}\ [W]} \qquad (2)$$

$$\text{Resilience}: \; LOLP\ (\%) = \frac{P_{pk_{solar\ panels}}[W]}{P_{consumption}\ [W]} \qquad (3)$$

Considering the previous variables for a specific installation and plotting its relationship in a 2D graph, Fig. 5, the resilience of the system for different hybridization factors can be obtained. The optimal factor can be found between 0.1 and 0.25 of the total capacity, meaning that the best results are achieved with a lithium battery with a capacity between 10 and 25 % of the total capacity of the installation.

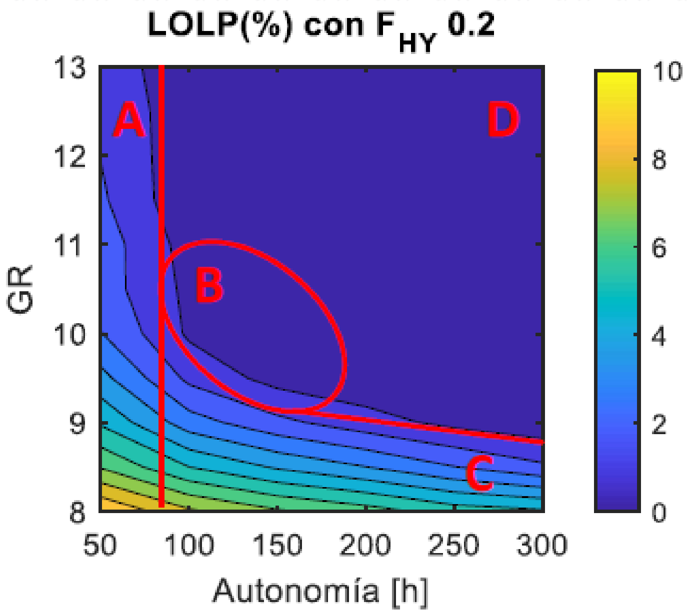

Fig. 5: 2D optimization map for relicience for Fhy=0.2 for specific conditions

With a Fhy of 20 % it is posible to reduce the chance of a power failure in the installation to 0 (with the existing conditions) in the region circled in red in Fig. 5. That would be the zone where the dimensioning of the installation in GR, autonomy, resilience and cost should be headed to.

Results

In the previous discussions, it's been concluded that the capacity in a pure lead-acid battery in an off-grid installation is reduced over the time. The reduction leads to a loss in the total usable energy in the installation of up to 40 %.

Because of the reduction of capacitance, the battery is cycled more often causing a quicker degradation and additional capacity loss. By including a Lithium battery, the autonomy of the whole capacity and the solar absorption is increased while the resilience and cost of the energy buffer is reduced

Summary of hybridization of Lead-acid / LiFePO4 :

1. Higher overall energy state in any moment of operation leads to a reduction of power failures for the same capacity installed.

2. Due to the improvement in energy state, it is possible to reduce the total capacity of the battery pack by 20-30 %.

3. Increase in life expectancy as the battery that cycles is the lithium with the lead-acid acting as an energy reservoir for special operation.

4. Use all the capacity of the lead-acid battery as the 48 – 72 h of floating state can be provided to have them charged at >95 % of SoC.

5. Removal of auxiliary gensets, fuel consumption and maintenance if properly sized

6. As more energy is absorbed during the whole day, the installed solar peak power can be downsized/optimized.

7. Low-investment and quick ROI as the % of Lithium is low (10-25 % of the total capacity) in comparison with the lead-acid.

Fig. 6: Plug&Play solution in existing installation. LiFePO4 + DC/DC converter

Information required for system sizing and optimization

For the right dimensioning of the lithium capacity and DC/DC converter power the following information is required:

- Location of the installation
- Average power consumption from the load during a day
- Average energy consumption from the load during a day
- Lead-acid battery voltage and capacity installed (if already installed)
- Solar panel peak power installed (if already installed)
- Autonomy required in hours or days

With the information above, it is possible to size an optimal solution an estimate the benefits to obtain.

We look forward to receiving your data on sales@epicpower.es and build a case study for you.