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SINGLE-STAGE THREE-LEVEL INVERTER APPROACH FOR CONNECTING HIGH VOLTAGE BATTERIES TO THE GRID

Abstract

The cost effectiveness and energy efficiency of AC-coupled high voltage battery systems depend on the power electronics that are needed to connect the battery to the grid. In most cases two-stage designs are used to convert the battery DC voltage to the desired AC grid voltage. This paper discusses the requirements and dependencies for a single-stage approach that can save costs and increase system efficiency.

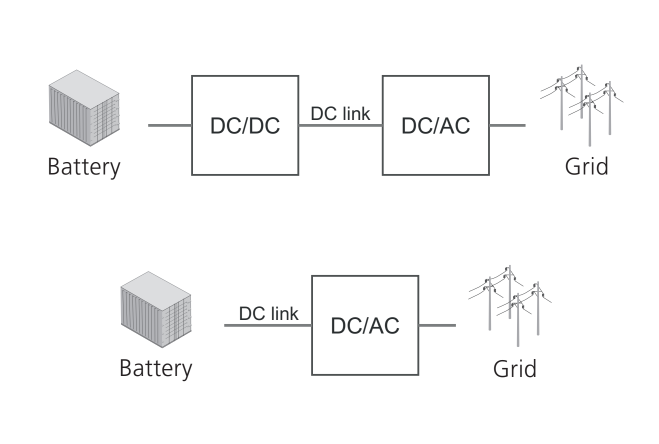

Figure 1: Comparison of two-stage and single-stage battery inverter systems

Introduction

To connect batteries to the AC grid, in most cases two power electronic components are used: an AC/DC inverter that is connected to the grid and a DC/DC converter that adapts the battery voltage window to the required DC link voltage of the AC/DC inverter. As most DC/DC converters can cover a wide input voltage range, the benefits of this two-stage design are the flexibility of the number of in-series connected cells and therefore the voltage window of the battery used. The downside of the two-stage design includes the additional hardware costs and the loss of efficiency within the DC/DC converter. One way to optimize this system is to try to eliminate the DC/DC converter and connect the battery directly to the DC link of the AC/DC inverter.

Dependencies of a single-stage battery inverter system

To realize a single-stage battery inverter design, it is necessary to consider and resolve three different voltage dependencies: the grid voltage, the supported DC link voltage range of the AC/DC inverter and the battery voltage window over the complete state of charge.
The grid voltage is defined by the country in which the battery is used (e.g. 400V in the EU and 480V in the US) and is therefore a fixed value within the system layout. The minimum required DC link voltage of an AC/DC inverter depends on (a) the grid voltage and (b) the inverter topology selected. In order to modulate the complete AC sine wave, the inverter's DC link voltage must be higher than the grid voltage peak value. For three-level inverters the minimum required DC link voltage V_{DCL_min} can be calculated using Equation 1.

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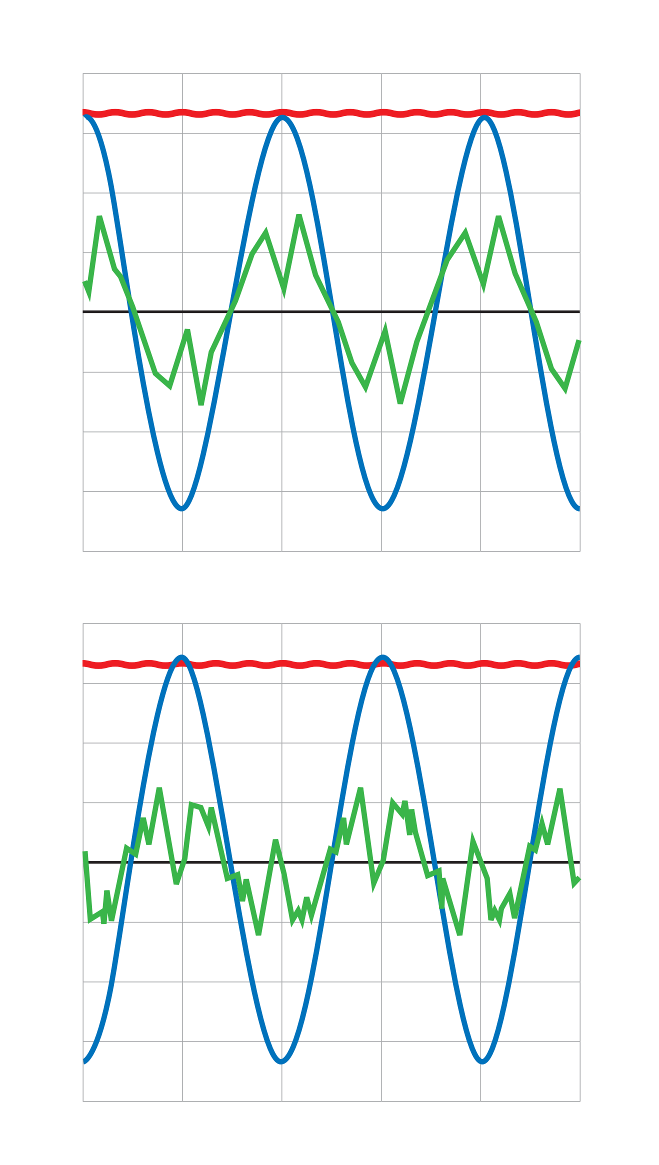

Figure 2: Reverse current effect with DC link voltage close to grid peak voltage
Signals: DC link voltage / grid voltage / grid current

Equation 1: $V_{DCL\_min} = 2 \times \sqrt{2} \times V_{PhaseN}$

Operating an inverter close to or below V_{DCL_min} has a negative impact on its current quality, as the body diodes of the power switches start to conduct at grid peak voltages higher than the DC link voltage. This effect, shown in Figure 2, starts (according to Equation 1) at 650V in 400V grids and at 785V in 480V grids, respectively. As can be seen, for a short time the power direction even flips the sign when the DC link voltage drops too far (lower figure). In this case the battery would be charged even if the inverter were set to discharge mode.
The maximum DC link voltage V_{DCL_max} of the new TruCharge AC3025 is specified at 935V and is basically limited by the voltage tolerance of the components used within the power train. In terms of cost and efficiency, working with higher V_{DCL_max} values in 400 or 480V grid applications is not a good tradeoff for an optimized inverter design. While the efficiency for switches with higher voltage tolerances decreases, the higher isolation requirements for systems beyond the 1000V boarder drive up the costs.
Based on the values for V_{DCL_min} and V_{DCL_max}, the battery voltage range is defined for a single-stage inverter design. In the case of the TRUMPF TruCharge AC3025, this is 650 to 935V for EU grids and 785 to 935V for US grids. This corresponds to possible charge/discharge voltage ratios of 1.44 for EU and 1.19 for US systems. It is important to know that this ratio is linearly coupled to changes within the grid voltage.

Summary

Using a single-stage three-level inverter design is a highly cost-effective, very efficient way to connect high voltage batteries to the grid. As the achievable battery voltage ratio V_{Bat_max} / V_{Bat_min} is directly coupled to the narrow, grid voltage-dependent DC link voltage range of the inverter, this approach is not suitable for all battery applications. Especially in US grid scenarios, the achievable V_{Bat_max} / V_{Bat_min} ratio of 1.19 is usually too low to be able to use the complete battery capacity. This can be compensated by a transformer, which may be required by some applications anyway. Hence, a LiIon battery with nominal voltage of 790V and maximum V_{Bat_max} / V_{Bat_min} voltage ratio of 1.44 is suitable to be connected to the 400V grid by way of a single-stage inverter design.

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