

QuiQ - High-Efficiency Grid-Friendly Battery Charger

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Abstract

While high-frequency power conversion has been adopted in other industries, the industrial and specialty vehicle industry generally still uses low-efficiency, line-frequency based battery chargers because of bottom-line cost concerns. Some similar priced high-frequency chargers have recently appeared with offer better efficiency but have poor power factor that results in higher utility charges and potential premise wiring problems. At a small cost premium, Delta-Q has developed a highly efficient unity-power factor charger that minimizes the amount of power drawn. The user enjoys real cost savings as CO2 emissions are reduced and extra power capacity is realized.

Keywords: AC-DC, Battery, Charger, Cost, Efficiency, Electric Vehicle, On-board, Power, Regulation, Sealed

1. Introduction

While the on-road Electric Vehicle (EV) market is presently in its infancy, the off-road and specialty EV market is a mature one and is made up of millions of vehicles such as golf cars, aerial access platforms, and sweeper/scrubbers.

A battery charger is an essential element of all battery powered EVs and large fleet applications can represent a significant load to utilities and cost to the user in their daily charging requirements. However, product cost is a main purchase criterion for the OEM's who build the vehicles, and consequently low-cost low-frequency ferro-resonant (FR) chargers are commonly used. While cost has been reduced to the bare minimum and some improvements have been made with output voltage regulation, these chargers use essentially the same technology as they did over thirty years ago. However, basic problems such as size,

weight, poor efficiency and the resultant non-sealed enclosure have limited their use to indoor or off-board applications. Because of the sensitivity to input voltage, many models are required to service the wide range of line voltages and frequencies found around the world.

Advances in power electronics have allowed high-frequency ("HF") chargers to be created that, if properly designed, can eliminate these problems at a small cost premium. As a result, many other industries have already switched from low frequency to high frequency power conversion. For the EV market, several HF chargers have recently appeared which eliminate some of these problems but which unfortunately create some new ones, specifically with the high distortion they generate back onto the AC line. This paper investigates how charger efficiency and power factor affect the total power losses and costs incurred with typical FR and HF chargers.

2. Power Factor Basics

Power factor (PF) is an important measure of how well the charger uses the utility power. In mathematical terms, it is the measure of ratio of 'real' power (Watts) to 'apparent' power (Volts·Amps or VA).

$$pf = \frac{P_r}{P_a} = \frac{P_o/\eta}{V_{rms} \cdot I_{rms}} \quad (1)$$

Perfect power factor (also called 'unity' power factor since the ratio is equal to 1.00) means that all of the input apparent power ($V_{rms} \cdot I_{rms}$), except for the factor lost in the charger's power conversion efficiency itself (η), is delivered out to the batteries (P_o). If the charger's input current waveform is distorted and deviates from the sinusoidal voltage waveform in time (displacement) or in shape (harmonic distortion or

THD), the power factor is reduced. Only real or average power (P_r) is useful for charging batteries—distortion from a low power factor means that a higher I_{rms} current has to flow in the system wiring to keep the real charging power P_o the same, as shown in Figure 1.

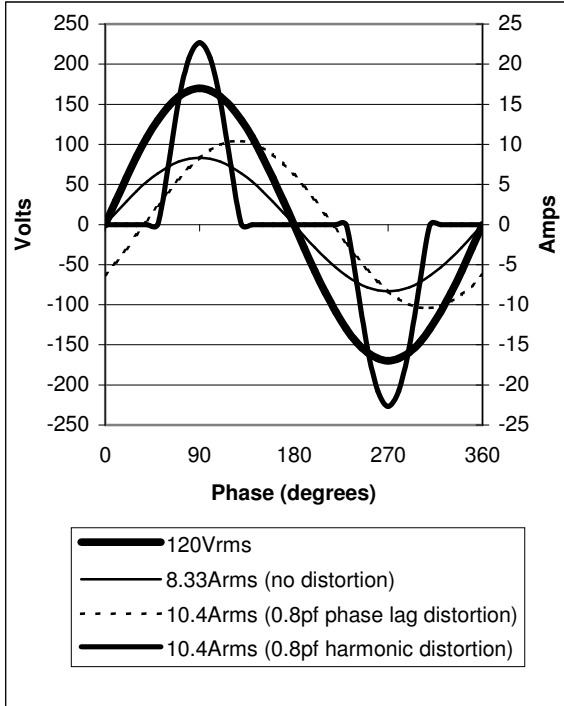


Figure 1 – Examples of 0.80 PF Distortion, 1KW

3. Cost Factors

Higher I_{rms} current results in significant power losses within a premise wiring system. In fact, these losses may be more than double the losses incurred for equipment with good power factor [1]. Most of the power lost is primarily from the step-down transformer and secondarily from the premise branch wiring. At 100% THD, typical of a non-PFC HF charger, harmonic currents almost triple the copper and eddy transformer losses and double the branch wiring losses. Not only will energy costs increase but the transformer must also be oversized by more than a factor of two, otherwise severe overloading will occur. Capacity is then either wasted in the electrical distribution system and higher power costs are incurred or the problem can be resolved with harmonic mitigation measures. Correcting power factor at the source—simply choosing loads with inherently good power factor has been shown to offer the greatest improvement in energy savings [1].

The utility companies may also apply an additional cost factor related to poor PF. With the emergence of new low power factor loads (e.g. computer AC-DC power supplies, adjustable speed drives), competitive pressures as power generation and distribution are privatized, and accurate new electronic meters, there is a trend for power utilities to measure and bill non-residential users for power factor. For example, a surcharge is applied in the Province of British Columbia for PF < 0.9 [2]. While PF is worst at the terminals of a load, it is significantly reduced (typically <10% THD) by the time it reaches the service meter when filtered through the premise's wiring and transformer and then diluted by other linear type loads [3]. A THD of 10% is equivalent to a PF of 0.995 as found by the following equation [4]:

$$Pf_{THD} = \frac{1}{\sqrt{1 + (THD_i / 100)^2}} \quad (2)$$

Unless the chargers are a large part of the overall power used, a power factor surcharge would likely not be applied.

Equation 1 shows that a lower efficiency ζ also results in higher I_{rms} currents and consequently higher power bills for a given output charging power P_o . QuiQ™ high frequency technology uses a two-stage power conversion approach that is highly optimized for efficiency. The first stage is an active Power Factor Correction (PFC) stage that continuously controls the input AC current to match the sinusoidal input voltage in both shape and phase. An additional benefit of this stage is a wide input voltage range which can be used anywhere in the world. Chargers that do not have this PFC stage will suffer from either extremely poor power factor (e.g. present competitive HF chargers) or excessive current ripple on the output (e.g. FR chargers) that may be detrimental to newer sealed battery technologies. The second power stage efficiently converts the PFC DC output to the required battery pack voltage with full galvanic isolation for safety. The resultant charger's efficiency is an industry leading 90% and not only directly reduces energy cost but also the lower heat generated allows the charger to be sealed and used in outdoor on-board EV applications.

Table 1 compares the power factors and efficiencies found with commercially available 1KW 48V/72V chargers and the subsequent power losses and costs. The charger's output voltages were standardized at a nominal 2.25Vpc (average output voltage during bulk phase of charge cycle).

Table 1: Comparative Charger Power Usage

Charger (Q48V/Q72V=Delta-Q, L48=Low Frequency Competitor, H72=High Frequency Competitor)	Charger pf	Charger Input Power (VA)	Charger Output Power @ 2.25Vpc (W)	Charger Power Loss (W)	Charger Efficiency (%)	Total Transmission Losses 100' 12AWG + Xfmr (W)	Total Losses (W)	Total Power Consumed (W)	Total Efficiency	Reduction in Power Bill	Potential circuit capacity increase
Q48V	1.00	1098	983	115	90%	56	171	1154	85.1%	15%	11%
L48V	0.95	1215	886	269	77%	66	335	1221	72.5%	0%	0%
Q72V	1.00	1116	1005	111	90%	58	169	1174	85.6%	13%	32%
H72V	0.74	1468	893	194	82%	113	307	1199	74.4%	0%	0%

As is shown, the Delta-Q QuiQ™ charger has about half the total power losses as the other competitive chargers while actually delivering 10% more power to the batteries. This translates into up to 15% net power cost savings and up to 32% greater circuit capacity. Based on a conservative estimate of 700,000 electric vehicles with a 2kWh daily usage, replacement with QuiQ™ chargers would save enough energy to power 10,000 homes or result in a reduction of 85,000 tons of CO₂ [5].

4. PF Regulations

There are many regulations that a charger must meet for worldwide usage. Besides ensuring that the charger can be used safely without causing a hazard to the user or to the equipment around it (e.g. UL1564 or EN60335-2-29), regulations also limit how the charger can draw power from the power utility. While there is presently no North American regulatory requirement for power factor, Europe requires all electrical equipment that connects to public low-voltage distribution systems to meet EN61000-3-2. To achieve a CE marking (which allows the battery chargers to be

sold and used in shops, garages, and light industry in the European Community), the manufacturer must self-declare compliance to EN61000-3-2 and to all other applicable EN61000 standards. EN61000-3-2 has been in effect since January 1, 2001 and specifies the maximum harmonics that a charger may inject back into the utility. For a battery charger of 600W or more, it must not exceed any harmonic limit shown in Figure 2.

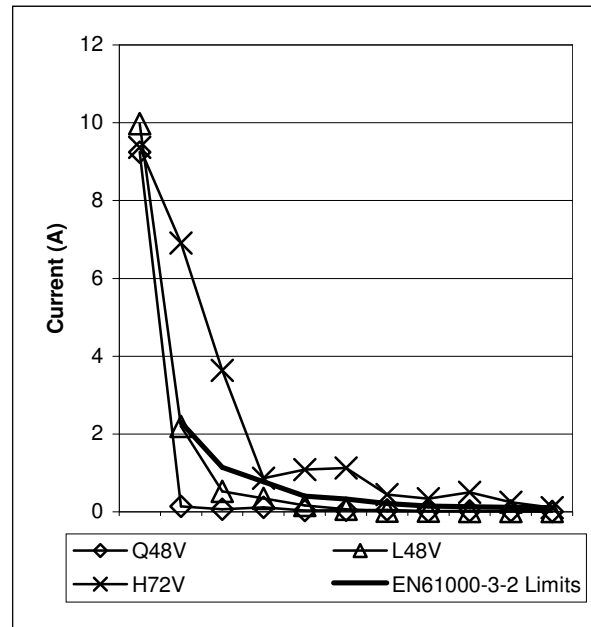


Figure 2 - Charger Current Harmonics vs. EN61000-3-2 Limits

As can be seen, the QuiQ™ charger input harmonics fall far below the maximum limits for all data points with a unity power factor. Competitive HF charger 'H72V' has a power factor of 0.74 and fails EN61000-3-2 limits by a large amount.

5. Conclusion

Power factor and charger efficiency are significant contributors to the operating cost of EV battery chargers. Wise selection of a charger with high power factor saves energy and reduces over sizing of the building wiring system or alternatively releases additional capacity.

Good power factor is also important for achieving CE compliance, allowing EV manufacturers to ease the task of selling chargers into Europe.

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Rob Cameron, P.Eng., is the Chief Technical Officer for Delta-Q Technologies Corp. and is responsible for the technical evolution of Delta-Q's power conversion products. Since graduating with a Bachelor of Applied Science from the University of British Columbia in 1986, he has been involved in hardware design, project and engineering management for several high technology companies. He is currently named on four patents. Rob enjoys playing volleyball whenever he can.