TECHNICAL WHITE PAPER

QuiQ™ Technology for Optimum Charge

1 Introduction

A battery charger is an essential element of all battery powered electric vehicles (EVs). While people commonly consider EVs as passenger carrying road vehicles, the vast majority of present-day EVs are industrial material handlers, utility/golf carts, floor scrubbers, etc. Deep cycle lead-acid batteries continue to be used with battery pack voltages of 24V, 36V, 42V, 48V, and 72V. The first chargers used were simple line-frequency based ferro-resonant ("FR") types, improved over the years to add better output voltage regulation. However, basic problems such as size, weight, and non-sealed enclosure (vented because of the heat generated from poor efficiency) relegated their use to indoor and off-board applications. Many models were 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, eliminate these problems and offer these benefits:

- Small size / weight (factor of 2-3x less)
- Wide-range input voltage/frequency range
- High power factor: required for meeting world regulations and to eliminate utility company surcharges
- High quality low ripple output: better regulation for advanced sealed batteries
- High efficiency: utility bills are reduced and the unit can be sealed without the need for a fan or vents.

The QuiQ™ charger from Delta-Q Technologies' incorporates new technologies that offer significant advantages over all other present-day low or high frequency chargers. This White Paper describes the QuiQ™ technology and compares it against older low-frequency FR as well as newer HF chargers.

2 QuiQ™ Technology

2.1 Wide Voltage Range Operation

An important QuiQ™ technology advancement is the ability to operate with all world electricity supplies. The QuiQ™ charger continuously monitors the input voltage and instantly adjusts to any variations to maintain a constant output. In contrast, conventional low-cost FR chargers are sensitive to input line voltage and can typically only maintain their output ratings within an AC voltage variation of +/- 10%. To address the world market, separate charger models are required for each voltage range. These chargers are also sensitive to line frequency and thus separate models are also required for 50 and 60 Hz line frequencies. As a consequence, at least six different FR chargers are required to address the different combinations of world supplies:

TABLE 1 – OUTLET VOLTAGE AND FREQUENCIES

Country	Voltage (Vac)	Frequency (Hz)
Japan (East)	100 ± 10%	50
Jamaica, Barbados	110, 115 ± 10%	50
Africa / Australia / China Europe / India	220-240 ± 10% (*Africa 220-250, Europe standardizing on 230V)	50
Japan (West)	100 ± 10%	60
United States / Canada	120 +4/–8%	60
Antigua, Brazil, South Korea, Philippines, Peru	220 ± 10%	60

If a conventional low-cost FR charger is operated at low AC line voltage, the output current will dramatically drop, resulting in much longer charging times. Even a higher cost wide-input range FR charger (Model 'B') exhibits this effect, as shown in Table 2. Low line voltages can also affect the maximum output voltage reached in a charge cycle, leaving the batteries undercharged. QuiQ™ technology reduces the output current by only 20% with input voltages below 108V to address component ratings and thermal concerns (efficiency is lower with lower input voltages) but it ensures that despite fluctuations in operating input voltage, a complete and consistently faster charge is delivered to the batteries.

TABLE 2- OUTPUT CURRENT (AMPS) @ 28.0V

Input Vac	QuiQ™ (24V)	Model B (FR)	Model C (HF)
120	25.0	20.0	16.7
110	25.0	20.0	17.2
100	20.0	20.0	17.4
95	20.0	19.1	17.6
90	20.0	13.1	0
85	20.0	7.3	0

There are many other advantages with the wide-range input capability. The QuiQ™ charger delivers a consistent charge during brownout and surge conditions commonly found in developing countries. It also compensates for voltage drops commonly found on long extension cords that could otherwise affect charging. With the universal IEC-320/C14 input connector, the QuiQ™ charger is suitable for world operation with just the addition of an IEC-320/C13 AC power cord mated with the countries' particular power connector.

2.2 High Power Factor

Power factor 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 (VA). If these two quantities are equal, it is said to have a perfect power factor equal to 1.00 or 'unity'. If the charger's input current waveform deviates in time (phase) or in shape from the sinusoidal voltage waveform (as shown in Figure 1 for a competitive high frequency charger), harmonics are created and the power factor is diminished as the apparent power increases over the real power. Only real power is useful for charging batteries– the distortion from the additional apparent power causes problems for the utility companies as well as the charger users.

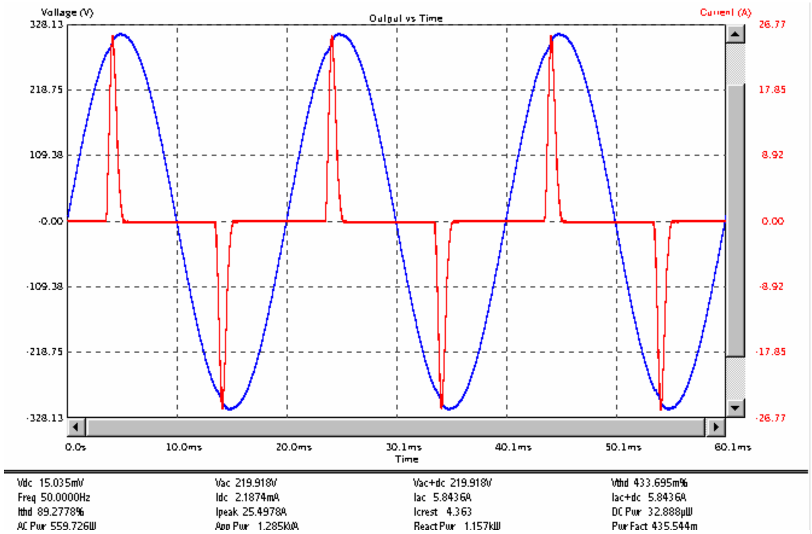


Figure 1 - Input Current of Model 'C'

Poor power factor causes problems for the utility companies by limiting the capacity of the transmission system and by stressing power transmission components such as transformers by making them run hotter. The power line distortion can also create havoc with other equipment connected to the utility. The problem is so significant that in Europe, battery chargers cannot be labeled with the CE mark (which allows them to be sold within the European community) unless they have an adequately high power factor. The particular standard that addresses this is EN 61000-3-2 and for a battery charger of 600W or more, it must not exceed any harmonic limit shown in Figure 2. Note that only odd harmonics, e.g., 3rd (150Hz), 5th(250Hz), 7th(350Hz)…, are shown for clarity reasons since the even harmonics, e.g. 2nd (100Hz), 4th (200Hz), 6th(300Hz)…, are below the limits for all chargers (this is because a symmetrical amount of current is drawn on both halves of the AC current waveform). The first data point is the fundamental line current frequency (i.e. 50Hz), and the only limit to the amount drawn is the limit of the outlet– consequently no EN61000-3-2 data point applies. As can be seen, the QuiQ™ charger input harmonics fall far below the maximum limits for all data points– the power factor is 0.998 with a THD of 3%. Competitive model 'B' has a power factor of 0.646, a THD of 57%, and fails at the 3rd harmonic. Competitive model 'C' has a power factor of 0.435 and fails by a large amount at most limits. Both competitive models fail this test and yet, oddly, both are marked 'CE'.

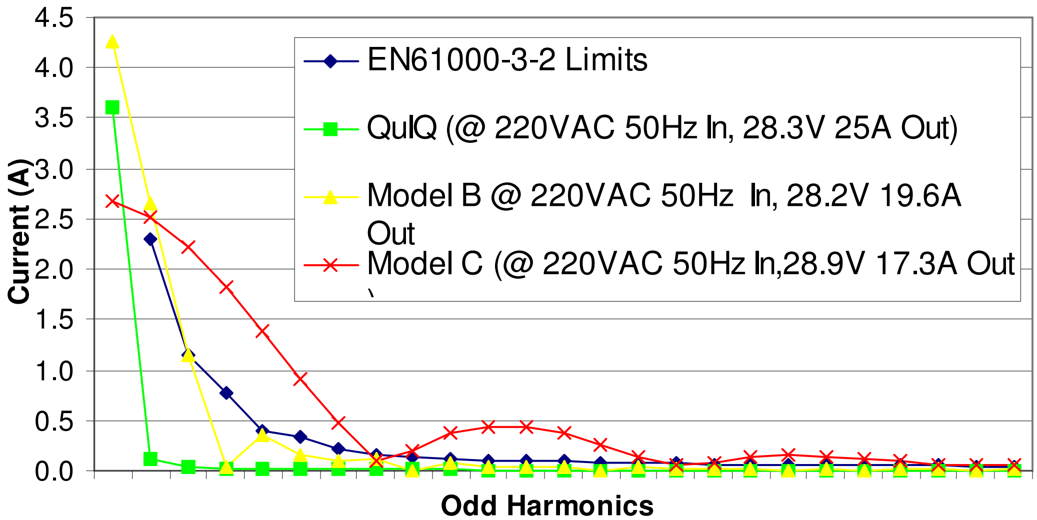


Figure 2 - Charger Current Harmonics vs. EN61000-3-2 Limits

In North America, the power factor problem is dealt with by commonly charging industrial users a surcharge on their power bill. Within the province of British Columbia, for example, an additional amount is charged according to Table 3. For a fleet application such as a golf course, no surcharge would have to be paid with QuiQ™ chargers while a surcharge of 44% would be paid for competitive Model 'B' and 80% would be paid for Model 'C'!

QuiQ™ high frequency technology achieves high power factor by incorporating a separate active power factor correction stage which continuously controls the input AC current to match the sinusoidal input voltage in both shape and phase. The added benefit of this stage is wide input voltage as previously discussed. Chargers that do not have this added stage will suffer from either excessive current ripple on the output (e.g. Model 'B') or extremely poor power factor (e.g. Model 'C').

TABLE 3 – PF SURCHARGE

Power Factor Range		BC Hydro
Min (=>)	Max (<)	Surcharge
0.90	1.00	Nil
0.88	0.90	2%
0.85	0.88	4%
0.8	0.85	9%
0.75	0.8	16%
0.70	0.75	24%
0.65	0.7	34%
0.60	0.65	44%
0.55	0.6	57%
0.50	0.55	72%
0	0.50	80%

2.3 Low Ripple Output

High ripple is a concern for battery charging, particularly for sealed lead-acid batteries. High current ripple effectively injects an AC current to the battery pack that contributes not to battery charging but rather to increased battery heating. In addition, as the charger approaches the end of the bulk charging stage, excessive voltage ripple will cause the battery to gas. For a sealed battery that can only manage a moderate amount of internal hydrogen recombination before venting, the battery may lose electrolyte over time and prematurely fail. As a result, battery manufacturers specify a maximum amount of ripple that can be applied to the batteries.

The following measurements were taken with a 100mV/100A shunt at 220VAC input. Model 'B' delivers 20A average current to the battery but there is an AC current of 28Arms. Hawker Energy and C&D Technologies recommend a maximum RMS current ripple of 5% of the C_{10} rating for their sealed batteries. This means that the minimum size of sealed battery this charger would be acceptable for is 28/0.05=560Ah! Typical battery packs found in the industry usually top out at 250Ah. In contrast, the typical QuiQ™ charger current ripple is less than 3% RMS of the rated 25A DC output current thus the minimum battery size to be charged (if quick charging is allowed by the battery manufacturer) is 15Ah, better than a C_{10} rate.

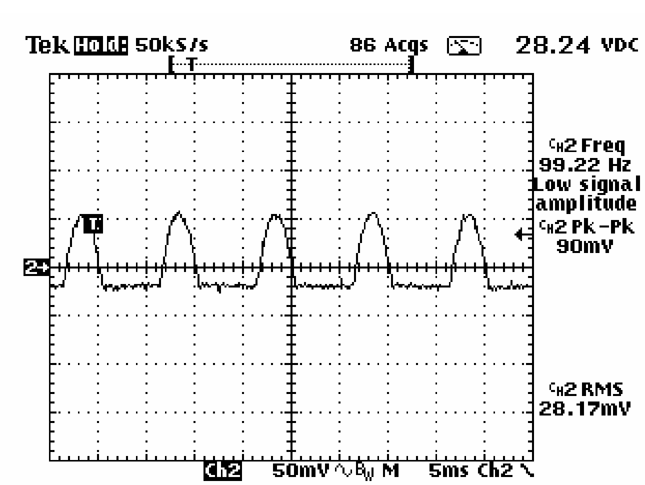


Figure 3 – Model 'B' Output Ripple Current

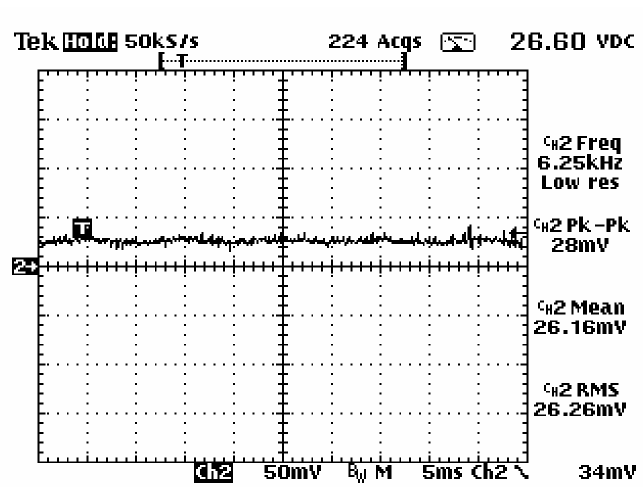


Figure 4 - QuiQ™ Output Ripple Current

QuiQ™ charger technology achieves low current and voltage ripple on the output because of its two-stage power design. Instead of the line frequency ripple being seen by the battery, the ripple is instead absorbed in a high-energy capacitor filter between the two power stages.

2.4 Efficiency

The efficiency of a battery charger directly affects the operating cost to the user. All chargers lose power in the form of heat as the input AC power is converted to DC power to charge the battery. A more efficient charger will produce less heat and a smaller utility bill. Efficiency varies at different operating points of the charger, e.g. input voltage, output voltage, output current, etc. A good way to compare charger efficiency is to look at the total charge efficiency, i.e. for a given amount of power put into recharging the battery, how much was actually consumed from the utility. Table 4 compares the 24V QuiQ™ charger against two competitive models in charging a 24V Trojan T105 battery pack at 110VAC input.

TABLE 4 – TOTAL CHARGE EFFICIENCY

	QuiQ™2425	LF Model 'B'	HF Model 'C'
Duration (h:m)	**9:14**	12:17	15:30
%Ah returned	104.25	111.5	110.6
kWh consumed	5.69	7.08	5.94
kWh delivered	4.96	5.31	5.05
Overall efficiency	**87.2**	75	85
Peak input (W)	805.8	742.3	572.4
Peak output (W)	703.3	560.5	491.6
Peak efficiency	87.3	75.5	85.9
Peak PF	0.999	0.685	0.577
Idle power (W)	8.4	22.3	5.4
Idle PF	0.82	0.31	0.32

As shown, the overall efficiency of the QuiQ™ charger is the best at 87% and compared to Model 'B' at 75%, saves the user 7.08-5.69= 1.4kWh per charge or approximately $50 per year for a daily charge. For a large fleet user, this can represent significant annual savings, especially if combined with savings from eliminating the power factor surcharge.

It is worth noting that the 24V QuiQ™ model used in this test is the least efficient of the QuiQ charger line. Higher output voltage units have higher efficiency, and all QuiQ™ chargers become more efficient with higher AC input voltages. Operating the 24V model at 220VAC increases the efficiency by approximately 2%. A 72V QuiQ™ model operating at 220VAC has a typical efficiency of greater than **93%**, an industry-leading figure for a two-stage charger! A user or OEM can take advantage of the QuiQ™'s higher efficiency at high input voltages (>200VAC) by being able to reduce the de-rating of output current when operating in high ambient temperatures and/or in sub-optimal mounting orientations.

2.5 Lightweight Sealed Enclosure

TABLE 5 – CHARGERS vs. WEIGHT / SIZE

Product	QuiQ™ 24V 25A (700W – HF)	Model 'B' 24V 20A (560W -LF)	Model 'C' 24V 18A (500W - HF)
Weight (kg)	**4.8**	13.5	5.2
Watts/ kg	**146**	41.5	96.2
Size (litres)	7.6	12.1	**5.9**
W/litre	**92.7**	46.3	85.5

Conventional low-frequency chargers are heavy and inefficient, necessitating a large enclosure with open vents to let the heat out. This is not suitable for on-board operation where space is at a premium, and where vehicles are exposed to a wide variety of environmental contaminants and water spray. The high efficiency of the QuiQ™ technology allows the charger to be completely sealed, eliminating the need for vents and/or mechanical fans. QuiQ™ technology also utilizes high frequency switching (~60KHz) for power conversion that allows the large bulky magnetic components to be several times smaller and lighter. Table 5 shows that QuiQ™ technology, for the same power, is twice as small and 3 ½ times as light compared to the best low frequency technology. The 24V model represents the worst case for power per size/weight ratios- power for higher voltage 48/72V QuiQ™ chargers is 40% higher.

Power enclosures represent a difficult design challenge to completely seal the sensitive electronics inside from the harsh elements outside. Unless the charger is hermetically sealed, air will ultimately enter or exit the charger– it is just a matter of when. No seal is perfect. When the unit heats up, air pressure inside goes up and leaks out through seals and/or around connectors. When the unit cools down, cooler moist outside air is drawn inside from the resulting vacuum. Over time, this pumping effect will cause condensation to build up in the unit and the 'sealed' charger may ultimately fail. QuiQ™ technology utilizes a special vapor seal that completely blocks the passage of moisture yet allows moving air to easily pass through (instead of through the seals). The QuiQ™ enclosure has an IP rating of IP46 which means it has been tested to protect against dust particles > 1mm in diameter (the '4' rating) and heavy water jet spray (the '6' rating).

2.6 Regulatory Approvals

The existence of regulatory approvals when selecting a charger, if considered at all, is often considered as a "bonus" but approvals should be every bit as important a purchase criteria as cost or charge current. Regulations ensure:

- the safety of the equipment user, e.g. the manufacturer has designed the product with adequate electrical spacings and construction methods to prevent shock and fire hazards. A non-approved charger that fails and causes injury or damage increases the liability of the equipment manufacturer and supplier and therefore higher legal exposure.
- the reliability of the equipment itself, e.g. the product operates the components within component limits.
- the equipment will stand up to common disturbances, e.g. the product will continue to operate in the presence of common problems such as static, switching/lightning surges and dips/interruptions on the power line, and radio interference.
- the likelihood of the equipment interfering with other equipment is reduced, e.g. less problems are encountered with the power line or on radios. This is especially important for high-frequency switching chargers that can radiate a significant amount of noise at very high frequencies if not properly designed.

Table 6 shows the standards that a charger should conform to be used in North America (NA) and Europe (CE):

TABLE 6 – REQUIRED INTERNATIONAL STANDARDS

Safety	NA	CE	DESCRIPTION
UL1564	✓		Industrial Battery Charger
CSA-C22.2 No. 107.2	✓		Battery Chargers- Industrial
EN 60335-1/ 2-29		✓	"Safety of Household and Similar Electrical Appliances" including "Particular Requirements for Battery Chargers"
Emissions			
FCC Part 15 / ICES 003	✓		Unintentional Radiators Class A
EN 55011		✓	Industrial, scientific and medical (ISM) radio-frequency equipment - Radio disturbance characteristics (Class A)
EN 61000-3-2		✓	Limits for harmonic current emissions (< 16A per phase)
EN 61000-3-3		✓	Limits of voltage fluctuations and flicker
Immunity			
EN 61000-4-2		✓	Electrostatic discharge immunity
EN 61000-4-3		✓	Radiated, radio-frequency, electromagnetic field immunity
EN 61000-4-4		✓	Electrical fast transient/burst immunity
EN 61000-4-5		✓	Surge immunity
EN 61000-4-6		✓	Conducted Immunity
EN 61000-4-11		✓	Voltage dips, short interruptions and voltage variations immunity

Canadian and US standards must be approved by a NRTL (Nationally Recognized Testing Laboratory) such as CSA, UL, or TUV (the QuiQ™ is approved by CSA Certificate #1388907 for both CSA and UL standards). CE marking is a self-declared process where the charger manufacturer declares that the charger meets the standards required by the Low Voltage Directive 73/23/EEC and Electromagnetic Compatibility Directive 89/336/EEC. The problem is that a company may only meet some of the standards and affix the CE mark based on this subset of the actual requirements. Ask for the Declaration of Conformity from the manufacturer (they are required to provide this) which lists the specific standards which they are claiming compliance to. The QuiQ™ charger has been tested and given an EN Report by the accredited agency TUV for the above listed standards, and as such, legitimately bears the CE mark.

The enforcement of these standards varies from country to country with penalties of product withdrawal, fines, or both, plus the resulting credibility loss. For the European Union, a non-compliant company added to the Customs database will have each product the company ships into Europe held and scrutinized at the border. Note: while FCC excludes devices that are exclusively used in any transportation vehicle, they highly recommend meeting the emission requirements to prevent problems with other electronics on board or in proximity with the vehicle.

QuiQ™ technology minimizes noise at the source rather than using costly 'band-aid' approaches. Techniques such as soft-switching are used for power conversion which inherently generate less electro-magnetic noise.

2.7 QuiQ™ Charge Features

QuiQ™ technology incorporates advanced multi-stage temperature-compensated charging for multiple battery types. A key advantage of this algorithm is ensuring maximum battery capacity while minimizing gassing and recharge times.

2.8 Multi-stage Algorithm

The charging technology delivers a 5-stage charge cycle to restore maximum capacity to the battery pack:

1. Qualification Phase– delivers a low current to the batteries to guard against shorted/reversed cells and to gently bring up a completely dead pack.

2. Bulk Phase– delivers full rated current until a temperature compensated voltage set-point is reached.

3. Absorption Phase– holds the voltage until the current falls to a calculated end-point.

4. Finish Phase– delivers a low current at unlimited voltage until a precise amount of additional charge has been delivered to ensure full battery capacity (total charge returned to battery is typically 108 to 110%, depending on factors such as battery condition and type). Common low frequency chargers return 120 to 130% to the battery, resulting in excessive gassing, water loss, and shorter battery life.

5. Top-up Phase– after 30 days of being plugged in, repeats the above steps to restore capacity and prevent sulphation.

2.9 Multiple Battery Types

QuiQ™ technology incorporates FLASH memory which allows different battery types to be permanently selected by the OEM. It allows support for both flooded and sealed lead-acid batteries as well as support for new battery chemistries such as nickel-zinc (please contact factory).

2.10 Temperature Compensation

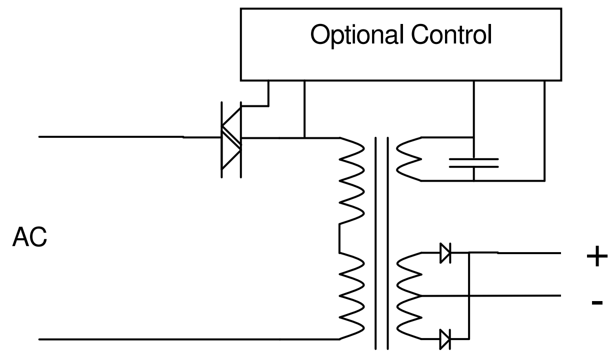
QuiQ™ technology monitors the battery temperature with the use of an external temperature sensor incorporated into the battery connector. A charger that does not have external temperature compensation will overcharge the batteries in hot climates and undercharge the batteries in cold climates.

QuiQ™ technology also monitors its own temperature to ensure it is always safely delivering maximum charging current despite high ambient temperatures or installations with inadequate cooling. The QuiQ™ charger reduces its output current if an internal high temperature set point is reached. This will lengthen the charge time slightly but a complete charge will still be delivered.

3 Appendix: Power Topologies

3.1 Low Frequency (High Ripple Output)

The ferroresonant charger has been around a long time because of its simplicity and low cost. Its high reactance provides protection against overloads and short circuits. The output winding is on the same leg of the core as the resonant winding, and the resonant capacitor acts to maintain this core section at a high level of saturation, resulting in a fairly constant voltage. To provide better output regulation, it is necessary to control this level of core saturation actively with the triac, and/or a shunting resonant current.

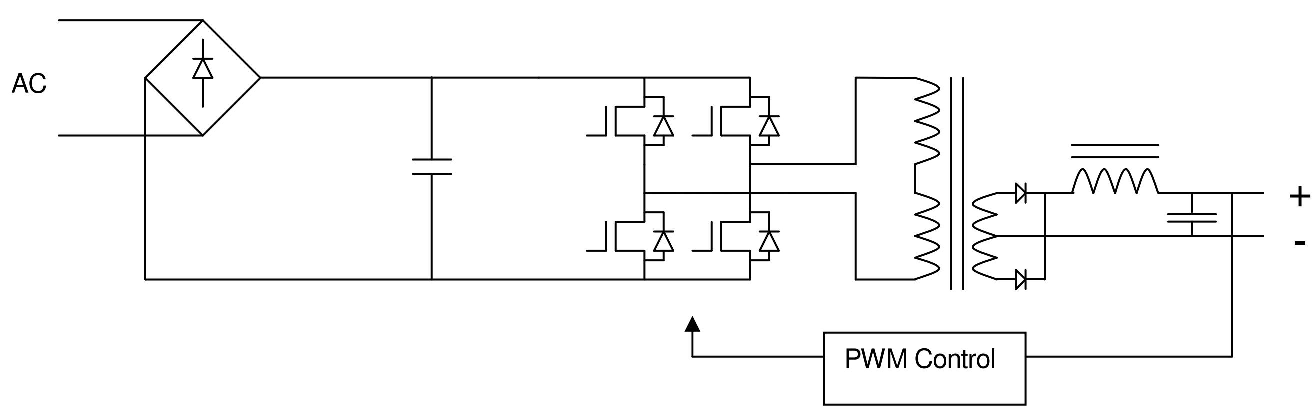


However, this technology has several disadvantages:

- Poor output regulation with input voltage, frequency, load variations without added cost
- Poor to medium power factor
- 50/60Hz transformer is large and heavy
- It is inefficient so it cannot easily be sealed
- Pulsating current is delivered to the battery (high ripple is not suitable for sealed batteries)

3.2 High Frequency Single Stage (Low Power Factor / Low Ripple Output)

The common approach to reducing size and weight and improving output regulation is to go to high frequency switching. The input AC is rectified and then filtered by a large high voltage capacitor bank to filter out the majority of the line frequency ripple. The high voltage DC is then converted to high frequency AC by Pulse Width Modulation (PWM) switching at approximately 100 KHz with a MOSFET bridge (many other devices and topologies could equally be used). The high frequency AC is down-converted in voltage by the transformer and after rectification, a final LC filter is used to remove the high frequency switching noise.

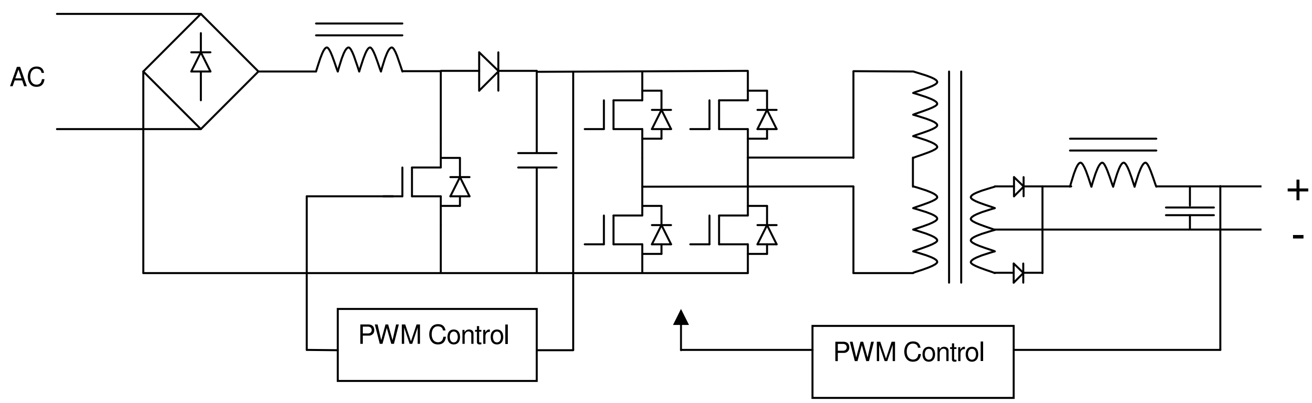


However, this technology still has disadvantages:

- Very poor power factor due to the resultant surge charging up the bus caps on the crest of each AC cycle. This circuit will not meet EN61000-3-2 required for sale in Europe.
- Input voltage range limited unless transformer switching circuitry or voltage-doubler circuitry is added

3.3 High Frequency Two Stage (High Power Factor / Low Ripple Output)

QuiQ™ technology employs a two stage conversion process highly optimized for efficiency to allow complete sealing of the enclosure. It is similar to the previous topology except that an additional stage is added to allow wide-range voltage input and to correct power factor. This stage, known as a power factor correcting boost converter, continuously monitors the sinusoidal AC input voltage and shapes the AC current drawn by the charger to match.



This topology's disadvantage is cost due to increased complexity. However, over time the cost of of raw metal (copper) to make large transformers has increased while the cost of semiconductors has decreased. Today's QuiQ™ charger only adds a small premium to that of the basic FR charger for vastly improved performance– a premium likely to disappear in the near future.