

Battery Charger Technologies

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Abstract

This paper reviews the history of the battery charger industry and provides a technical overview on the methodology of the different battery charger technologies, such as Magnetic Amplifiers, Ferro-resonant, SCR rectifiers and High Frequency Switchmode chargers.

Introduction

Many industrial applications such as Utility Switchgear, Oil Platforms, Gas Turbines, Process Control, etc., involve the operation of critical DC loads. Dropping any of these critical loads may result in extreme and costly circumstances. Therefore, these applications require the use of batteries as a backup power source in case of a power outage. Hence, a need was developed for equipment used to maintain the charge in the batteries.

Battery charger / DC power supply technologies have been developed over the years to improve the efficiency, reliability and cost of the equipment. These different technologies serve the same purpose of supporting the DC loads and maintaining a full charge in the battery of a DC system. Each technology, however, has its advantages and disadvantages.

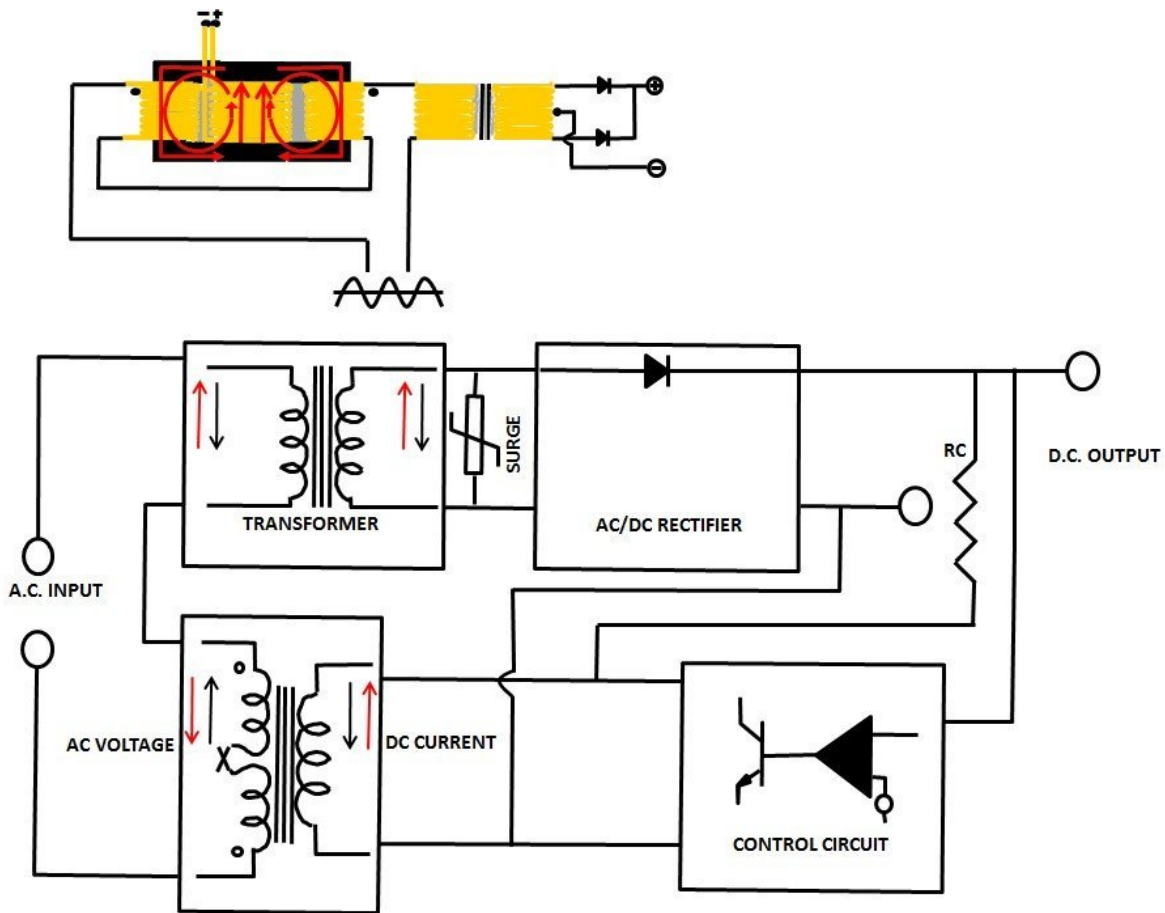
Magnetic Amplifier (Mag-Amp) Technology

Magnetic Amplifier is one of the first technologies used in rectifying the AC power in DC power applications. Mag-Amp has had many development stages over the years and has over 190 patent filings. This technology started when Dr. Alexanderson submitted a paper presenting this concept to the Institute of Radio Engineers in 1916. Dr. Alexanderson's paper detailed replacing Vacuum Tube Rectifiers which had many disadvantages compared to Mag-Amp, mainly its large size and weight. Mag-Amp rectifiers were widely used in WWII for power regulation equipment.¹

Theory of Operation

Magnetic amplifiers are AC regulators using transformer technology to control power supply output. They work by varying the magnetic core saturation that changes the AC reactance of a coil. The reactance of the AC coil in the reactor (magnetic amplifier) is controlled through a DC winding. When a DC current is passed through this winding, the core saturates and the reactance of the AC coil is decreased causing the current through the AC coil to increase. The reactor can be placed in either the primary or the secondary circuits of the power transformer.

It is advantageous to integrate the reactor in series with the primary side of the power transformer. In this case, input to output isolation is easily maintained and controlled due to the physical separation between the AC and DC coils in the reactor. When a transistor control is added to the DC coil of the reactor, the primary voltage of the power transformer can be precisely regulated to produce voltage and current control of the rectifier's output.



The nature of the primary magnetic amplifier is inductive; this produces lower input power factors in mag-amp designs compared to other technologies. The input current harmonic distortion is typically less than 10% and the output efficiency is approximately 70% for single phase designs and 85% for three phase designs.

The transformer regulator is very tolerant to AC input spikes and surges, hence the reliability of the design is excellent. This design provides output voltage and current adjustability, a wide input voltage frequency range, and good line and load regulation (typically 0.5%). There is no electromagnetic interference generated due to its linear regulation properties.

Mag-Amp Technology Advantages

- Simple Design; High Reliability and Long Service Life
- Withstand Input Transients Without Damage
- Wide Input Frequency Range
- No EMI Generated
- Inherent short-circuit tolerance
- Gain of Saturable Reactor reduces strain on control semi-conductors.
- DC Voltage and Current control
- Fail-safe Operation
- AC to DC Isolation

Mag-Amp Technology Disadvantages

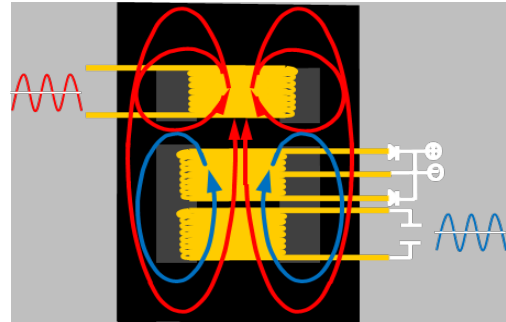
- Size / Weight (2-similar magnetics)
- Cost
- Lower Efficiency/Power Factor
- Slow transient response

Controlled Ferroresonant Technology

Ferroresonant Technology started as an uncontrolled rectifier circuit which was invented by Joseph Sola in 1938 to improve the performance of battery chargers. It primarily depends on controlling the magnetic flux by implementing magnetic shunts in the power transformer of a battery charger. ^{2,3,4,5}

Theory of operation

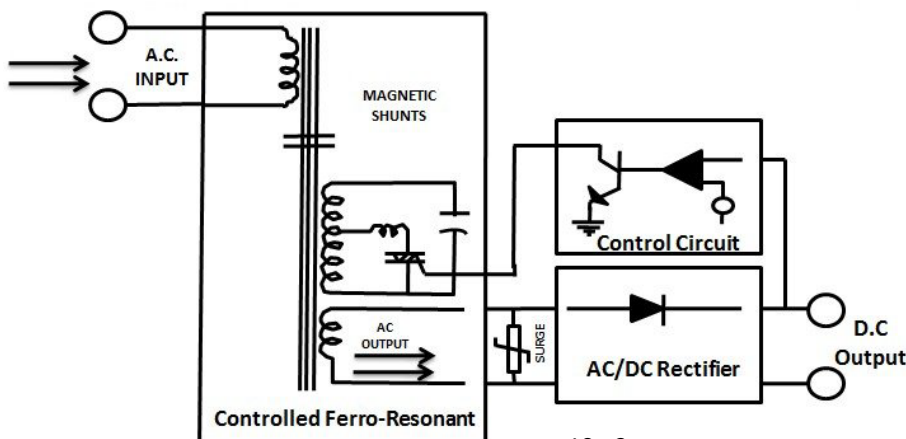
The controlled ferroresonant technology utilizes a special power transformer that employs a secondary tank circuit. The primary and secondary windings of this transformer are magnetically coupled through magnetic shunts. The amount of magnetic coupling between the windings is determined by the amount of steel and air gap in the magnetic shunts. This magnetic coupling provides an inherent output current limit. The construction of ferroresonant transformers also requires a premium grade steel.



The secondary of the ferroresonant transformer consists of a tank circuit that is resonated by a high voltage winding and capacitors. This capacitor tank circuit keeps the magnetic flux of the secondary winding in saturation. The effect of the saturated secondary is inherent voltage regulation (an open feedback loop regulator) and the loads on the secondary are not linearly reflected back to the primary.

The primary winding of the transformer acts as a resistive load to the AC line; hence the power factor is greater than 0.9 for ferroresonant designs.

The ferroresonant power transformer can be controlled by varying the voltage on the secondary tank circuit winding. This is done by electronically switching an inductor across a portion of this winding using a bi-directional AC switch, such as a triac or back to back SCRs. It is only necessary to control about 20% of the output power at this point in the circuit. The control current, which circulates around the resonant tank, is minimal. Therefore, the control is efficient and output voltage regulation of 0.5% can be achieved with electronic output current limit in addition to the inherent magnetic current limit of the power transformer.



The characteristics of a saturated secondary and physical separation between the primary and secondary windings in the power transformer design also provide excellent attenuation to incoming transient voltages that may be present on the AC line.

Ferroresonant Technology Advantages

- High Efficiency & Power Factor
- High Reliability and Long Service Life
- Low Input Harmonics
- Saturated secondary will not let primary surges through to the output
- Low Generated EMI
- High-gain; small control switch current can control several KVA output
- DC Voltage and Current control
- Fail-safe Operation
- Inherent short-circuit tolerance
- AC to DC Isolation

Ferroresonant Technology Disadvantages

- Cost (Due to the special steel transformer)
- Sensitive to Input Frequency Variations
- High Voltages present in Tank Circuit

SCR (Silicon Controlled Rectifier) Technology

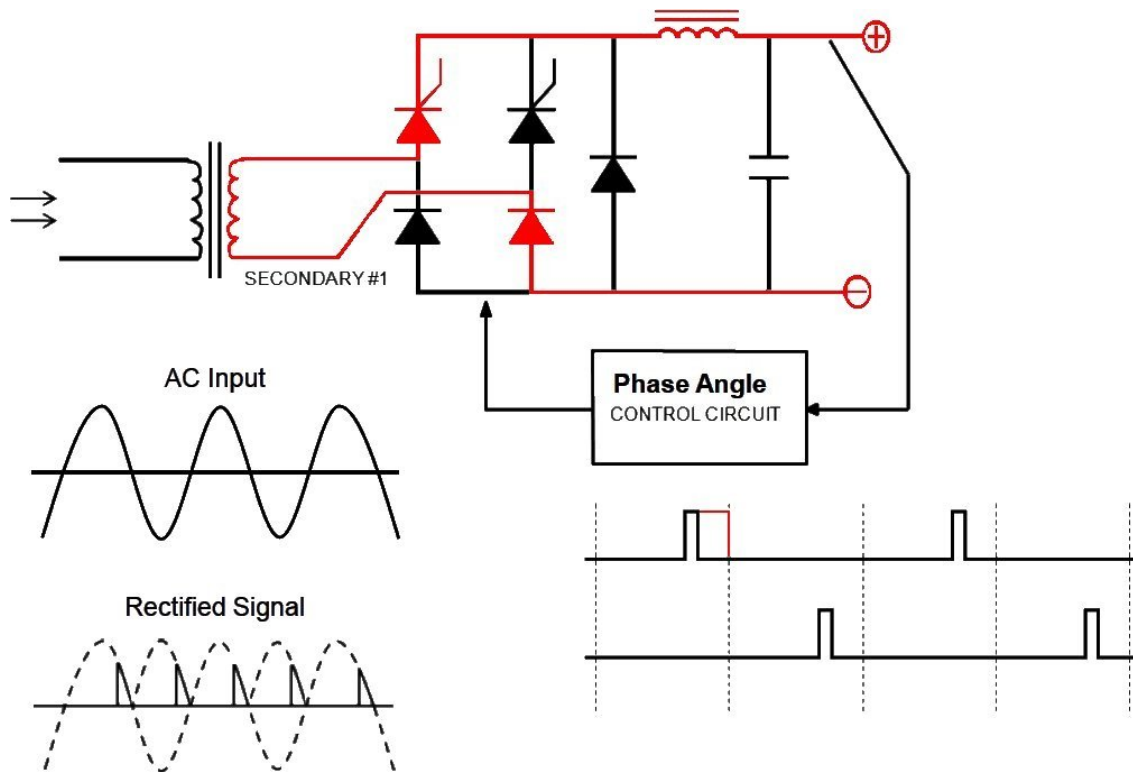
The SCR is a four-layer solid state semiconductor current controlling device. An SCR is equivalent to an NPN transistor and a PNP transistor connected back to back, and its function is equivalent to a gated diode. SCR devices were developed by General Electric's engineering team based on prior work done at Bell Laboratories. The technology was commercialized by Frank W. Gutzwiller in the 1950s to replace the mechanical relays used in communications applications. ⁶

Theory of operation

A bridge of multiple SCR devices can be used to rectify the AC input to a battery charger and regulate the DC output to the required level.

A phase modulator circuit driven based on output DC voltage regulation and current control is used to control the SCR conduction angle. The conduction angle controls the amount of time that the SCR conducts in each cycle. A longer conduction time provides a higher output and a shorter conduction time reduces the output.

Controlled SCR battery chargers have very predictable output curves under all AC input line conditions. The output efficiency for a single phase model is approximately 75% and the power factor is about 0.7. For three phase models, the output efficiency is approximately 85% and the power factor is about 0.8. Using an output filter inductor can improve the input power factor, but at the cost of lower efficiency. Input current harmonic distortion is typically greater than 20% depending on the rectifier configuration; 12 pulse rectifiers are lower in harmonic distortion than 6 pulse rectifiers. It is also possible to see some EMI activity in these designs due to the SCR switching each power line cycle.



SCR Technology Advantages

- Low Cost
- Wide Range of Output Voltages and Currents
- Wide Input Frequency Range
- SCR proven track-record
- Line commutated, false fire limited to half-cycle.
- AC to DC Isolation

SCR Technology Disadvantages

- EMI Noise Produced by SCR Switching
- Large Output Filter used to Improve Power Factor and protect load
- False gate trigger by high dV/dT , temperature and noise
- Main Control device failure relies on fuse/breaker operation.

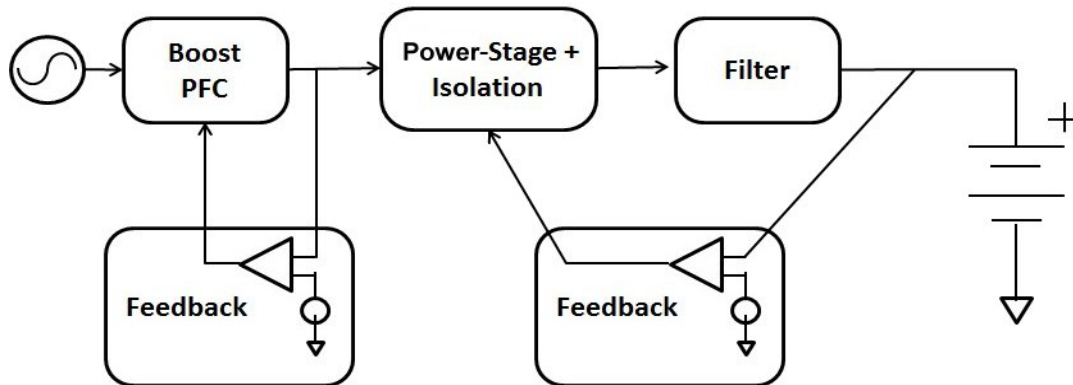
High Frequency (Switchmode) Technology

Switchmode technology dates from the mid-1920s. A patent⁷ was assigned to General Motors in the early 1960s. These early versions were DC to DC convertors, and only converted from one DC level to another. They were used in tube operated car radios. Later versions converted AC voltage to a DC output voltage. Switchmode technology has now evolved to incorporate power factor correction in the AC input.

Theory of Operation

The basic philosophy of the High Frequency Switchmode technology is that high frequency switching allows for much smaller power magnetics and filtering. High frequency switching also allows much higher efficiency due to low losses in the switching devices versus low frequency technology methods.

High frequency switchmode chargers have two major stages, each accomplishing specific functions. The first stage provides an input EMI filter, power factor correction (PFC) and a high DC bus voltage for the second stage. The second stage is a DC to DC convertor section which takes the DC power from the first stage and switches it at a high frequency. This switched power is applied to the primary of a high frequency power transformer. The DC output voltage and current are controlled by adjusting the pulse width of the switching waveform applied to the power transformer primary – Pulse Width Modulation. The output from the secondary of that transformer is rectified, filtered and passed through an EMI filter to the DC output.



High Frequency (Switchmode) Advantages

- Compact and Light Weight
- High Efficiency
- High Power Factor (PFC)
- Usually Hot Swappable
- Can be installed/replaced by one person
- Wide Input Voltage and Frequency Range
- Very fast load/line response
- Clean DC output
- AC to DC Isolation
- Cost is practical for N+1 redundancy

High Frequency (Switchmode) Disadvantages

- Shorter Longevity
- Complexity
- EMI Filters Required on Input and Output
- Forced Air Cooled

Summary

Battery chargers serve the critical purpose of maintaining battery charge levels. Therefore, given the common usage of batteries in industrial application, battery chargers and power supplies have become a necessity in nearly all installations.

From the battery point of view, the main factors that affect the life span of a battery are the characteristics of the DC power that is supplied by the charger; such as, DC voltage level, AC ripple, overcharging, undercharging and frequency. The characteristics of a Battery Charger's DC output power are mainly related to the design intelligence and quality. Different Battery Charger technologies could provide DC signals that are very close in characteristics if they were designed correctly. However, one technology's design criteria could be more complicated than another in order to achieve the same output characteristics. But if all design and safety aspects were taken in consideration, different technologies can provide similar performance.

Magnetic amplifier chargers are very reliable, and have been known to offer a service life in excess of 30 years. This high reliability is due to the simple design and the inherent properties of the magnetic configuration. Magnetic amplifier designs are also easy to troubleshoot/repair due to the simple design. Magnetic amplifier chargers are larger and costlier due to having a transformer and reactor in every design. In addition the magnetic amplifier circuitry has lower efficiency than that of other technologies.

Ferroresonant chargers offer tremendous performance in a smaller package. Ferroresonant technology offers a long service life, though not quite as long as magnetic amplifier designs. The high efficiency and power factor of the ferroresonant charger does add to cost, due to the special steel required in the transformer design.

SCR chargers offer a balance of cost, performance, size and longevity. Although not as efficient as ferroresonant technology, the lower performance is offset by a lower cost and weight. The SCR charger is also marginally less reliable, but does still offer a long service life.

High frequency switchmode chargers in general offer the highest efficiency and power factor as compared to all other technologies. In addition they are much more compact. Components used in High frequency chargers are less costly and are much smaller than components used in other designs. However the circuitry is more complicated and not as reliable. This lower reliability is offset by the ease of installation (many high frequency designs offer hot swapping capability) and a lower cost. The low cost also makes N+1 redundancy possible.

Each of the different battery charger technologies has both its advantages and disadvantages. The technologies detailed all serve the same basic purpose. It is the requirements of the end customer in terms of performance, cost, longevity and size that determine what technology is used.

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