A SCHAFFLER White Paper

SCHAFFLER & Associates Pty Ltd

Power Electronics for the Railway Industry

www.railwayinverter.com

Unit 4 / 4 Prosperity Pde
Warriewood, NSW 2102
+61 2 9997 1010
www.railwayinverter.com

The Activerter

An Active Front-End Inverter

By David Kok
International Sales Manager

Contents

Introduction

There are many circumstances on trains where the supply power is alternating current (AC) and this power must be regulated before it is used by on-board devices.

The Activerter is a power electronic device developed by SCHAFFLER. It takes input AC and provides regulated DC. The primary use of this DC is for inverters for motor control.

Problem Statement

Large rectifiers generate significant harmonics back into the supply line. New regulations are intended to combat the use of uncontrolled rectifiers or line switching devices from being used in new installations. Notwithstanding the future regulations, many organizations have had to take corrective action because the level of harmonics in their supply had become so intolerable, causing interference and damage to electrical and mechanical plant.

The limits for harmonics are being imposed under IEC1000-3-6 in Europe and Australia and IEEE 519 in the USA.

The detrimental effects of harmonics are:

- Severely reduced power factor
- Overheating of AC induction motors
- Overheating of transformers
- Overheating of power factor capacitors
- Inaccuracy in instrumentation and control systems
- Synchronisation difficulties in line commutated power electronic products such as inverters, soft starters etc.
- Harmonics voltages are passed on to all consumers sharing common feeder lines.

Previous Options

The typical power equipment affected by the regulations includes:

- Thyristor converters used in DC drives
- Thyristor battery chargers
- Current fed inverters in UPS
- Current fed inverters for motor control
- Railway catenary supplies
- General high power DC supplies

SCHAFFLER Solution

The SCHAFFLER solution is an active front-end inverter. Figure 1 shows the basic scheme. In this single-phase arrangement, the input IGBT bridge forms the power section of the active front-end inverter which is connected to the supply.

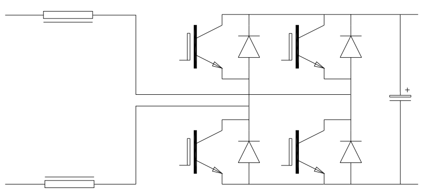

Figure 1

With appropriate sinusoidal PWM modulation, the AC/DC converter controls the phase and magnitude of the current so that it is in phase with the input supply voltage. This system of control produces near sinusoidal current at near unity power factor at the input of the AC/DC converter.

Benefit 1

The Activerter minimizes the harmonic distortion in the AC supply current. All the low frequency harmonics are removed – ie:3^{rd}, 5^{th}, 7^{th}, 11^{th} etc. The harmonics generated by the system are confined only to multiples of the switching frequency on the IGBT bridge which is 2kHz.

Benefit 2

The Activerter maintains a constant DC link voltage irrespective of the current absorbed or regenerated by the output inverter. The AC/DC converter has the advantage of requiring relatively small size DC link capacitors that reduce costs and the size of the equipment.

Benefit 3

The Activerter maintains a power factor close to unity. This is a natural feature of the active front-end inverter to keep the current in phase with the line voltage. Uncontrolled rectifiers will give a power factor from 0.5 to 0.72 depending on the line impedance and filter inductance.

Benefit 4

The Activerter produces a DC supply that has four quadrant characteristics for regeneration of power back to the utility AC supply. The Activerter has the advantage of providing this facility with only the use of uni-directional power devices.

Implementation

The line reactor is an essential part of the Activerter. Simulations enable the choice of inductor to an optimum value of 15% of line reactance. As power is applied, the DC bus voltage rises due to the full wave rectification. The diodes form the charging circuit for 200 milliseconds after which the IGBTs are gated on by the control system so that the DC bus climbs to 590Vdc due to the *boost* action of the PWM bridge. As the name implies, the output voltage is boosted to a higher voltage than the diode rectified voltage.

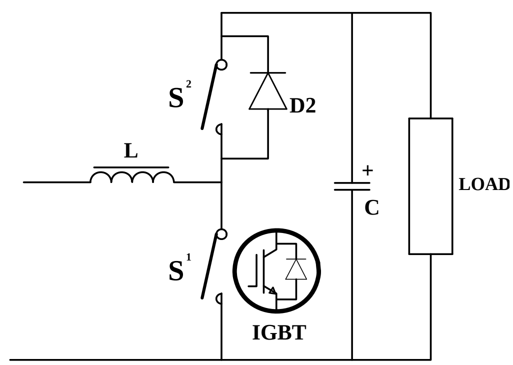

Figure 2

Figure 2 shows how the boost action operates. The closure of S^1 causes the diode to be reverse biased, thus isolating the output from the input. During this time, the input supplies energy to the inductor. The boost action takes place when S^1 turns off and the load receives energy from the inductor as well as the input. By controlling the switching modulation in relation to the supply frequency, the DC bus maintains a desired level.

The output bridge feeding the load creates a fast dynamic responding sinusoidal output current to control the load at the desired voltage and frequency. The capacitor bank stores the right amount of energy to limit the transient ripple below a suitable limit. The ripple is caused by the imbalance in demand between the input and output power.

Control Strategy

Current control is the key part of the Activerter. It achieves a fast response by using Predictive Current Control of the input line current. Ramp comparison modulation involves measuring the error between a target reference current and the actual output current, then using this error to change the PWM output of the inverter. It offers the benefit of a fixed switching frequency, but has the disadvantages of needing to have the control loop accurately tuned to suit the load and having a steady state phase error between the target current and the output current.

Predictive current control involves determining the correct inverter output voltage to achieve the desired target current in the next switching cycle and offer the potential for the best performance.

This system is used in preference to Hysteresis Current Control. The advantages of the Predictive Current Controller over the conventional hysteresis current controller are:

1. The Predictive Current Controller is set at a constant switching frequency. It makes use of a lower switching frequency and therefore produces lower switching losses. This is particularly important for large power converters.

   The hysteresis current controller has an error band which sets up upper and lower error boundaries. The frequency is therefore variable and uncontrollable as the current oscillates from the upper to the lower boundaries causing undefined losses. If the error band is reduced the switching frequency increases even more.

2. The predictive Current Controller regulates the vector angle while the magnitude of the vector is maintained constant. This increases the accuracy of current control which is important for large powers.

   The hysteresis current controller does not take into account the vector angle. It only regulates the amplituyde of each individual phase current. It may fall into a so-called limited cycle which generates extremely high switching frequencies. This phenomenon is most undesirable in large converters.

3. In the predictive current controller, the phases are treated as a whole rather than separately as in the hysteresis method, giving good overall control. Predictive current controller makes use of zero space vector to reduce the switching harmonics substantially.

4. To achieve the same accuracy, the hysteresis may require at least 10kHz switching frequency whereas the predictive current controller requires less than 5kHz.

Results

The results of step changes in the response of a three-phase Activerter are shown in the figures below. Figure 3a and 3b relate to a 50% step change in line voltage at the 0.04s mark. The overshoot in bus voltage occurs for less than 10 milliseconds. Naturally the input current reduces for a given load because the voltage has increased.

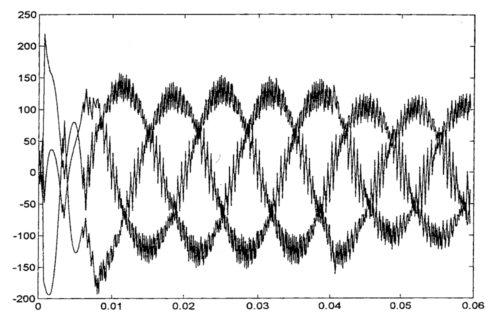

Figure 3a
AC load current displayed when a 50% increase is applied to the supply voltage.

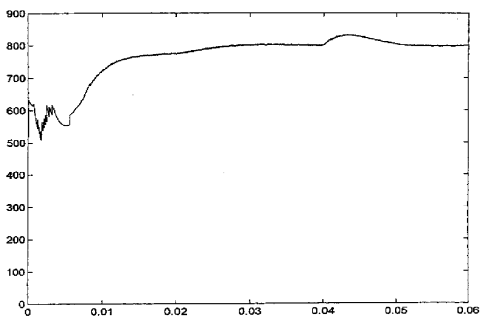

Figure 3b
DC bus voltage when a 50% increase is applied to the supply voltage

Figure 4 shows the AC load current and DC bus voltage on the same axes. At point 0.04s a load is applied. There is no noticeable change in the DC bus voltage. This is a good illustration of the point made previously regarding the fast response of the Predictive Current Controller.

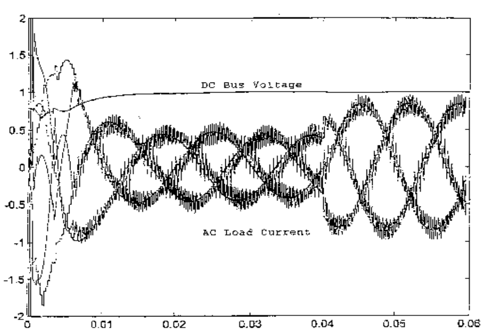

Figure 4
AC line current and DC bus voltage for a load increase from 50% to 100%

NB: The initial transients in figures 3a, 3b and 4 are startup transients as the active front-end inverter turns on and initially boosts from the rectified 580Vdc.

Summary

The above results show clearly that the Activerter will solve many problems related to:

- Removal of harmonics
- Power factor efficiency
- Stability of power supplies when regeneration occurs

The Activerter is a major step forward in terms of efficiency and elimination of electrical pollution, which is rapidly destroying the utility networks throughout the world.