SCHAFFLER
Power Electronics for the Railway Industry

Galvanic Isolated System
Third Rail and Overhead Centenary Supplies

This paper focuses on supplies between 500 and 750 Vdc for EMUs (Electrical Multiple Units). The most common of all is 600 Vdc. All such supplies suffer from the significant variation in the supply caused by trains accelerating (pulling the supply voltage down) and decelerating (forcing the supply voltage up). A typical 600 Vdc rail can be expected to reduce to 450 Vdc and increase to 1000 Vdc (1200 Vdc if the nominal is 750 Vdc). The railway authorities will seldom specify or admit such a supply range in tenders.

This paper also focuses on quality requirements that add to the reliability and sustainability in power inverters.

The symptoms that show up in induction motors, cables and control equipment is cause largely by the use of non isolated inverters supplied from dc supplies. Another important reason for failure in equipment is the lack of common mode and differential mode filtering at the output of the 3-phae inverter.

In a non-isolated inverter system, the following problems are likely to occur:

- Failure of insulation to earth and phase to phase deterioration in 3-phase motors. This also applies to cables and other connected equipment.

- Failure of bearings in motors

Inverter Output

A 415 Vac 3-phase 50 Hz inverter and motor are used as an example. The correct supply to such an inverter is 600 Vdc. This voltage will enable the inverter to output 415 Vac maximum. If the dc voltage reduces below 600 Vdc, the 415 Vac RMS output will reduce for a given 50 Hz frequency and this will cause the magnetics in the motor to be under fluxed. The motor current will rise to the point that the inverter will trip out on over current. A way to overcome under fluxing of the induction motor is to reduce the inverter frequency proportionally when the supply drops below 600 Vdc. This is not always desirable and depends on the nature of the load.

If the dc supply increases then provided that modulation depth control is a feature of the inverter, the RMS output voltage will be kept constant. However in order to achieve this RMS voltage, the peak level of pulses will equal that of the dc supply and the pulses will narrow. So the winding of the ac motor and other equipment will be subjected to these high voltage peaks that will gradually weaken the insulation of the motor and other loads connected.

Even if a non isolated input chopper is used to regulate the dc supply to the inverter, the fact remains that the whole system will rise above earth potential by the magnitude of the dc supply voltage. This is what does the damage and will start occurring within about three years in operation.

Investigation of electronic choppers used to regulate the supply to the inverter have revealed that they are buck choppers and do not have the ability to boost the supply if it drops below 600 Vdc.

The only satisfactory solution is to use a galvanically isolated buck / boost chopper that will provide a constant 600 Vdc to the inverter and isolate the output loads from earth potential.

If the motors used are 230 Vac 3-phase then the supply to the inverter need only be 450 Vdc. However, if 480 Vac 60 Hz motors are used then a boost chopper will definitely be required to prevent under fluxing of the induction motor.

Weight Reduction

The buck / boost converter should be a high frequency inverter switching at 25 kHz or more. Using ferrite cores, it is possible to reduce the size and weight significantly. Increasing the switching frequency of this converter will reduce the weight and size more than 4 times compared to 10 kHz. The isolation transformer and IGBT inverter must be designed to withstand the dc level with respect to earth. The transformer must be foil wound re reduce losses at the high frequency.

In addition, peak current mode detection is essential to ensure that saturation does not occur in the isolation transformer. Poor quality inverters ignore this function and over come it by simply increasing the current capacity of the IGBT. A poor solution.

Filtering the PWM Output

Stator windings in motors can fail when exposed to the fast-rise time voltage surges derived from inverters. Surges can create partial discharges and these discharges eventually destroy the turn-to-turn and/or phase-to-phase insulation, resulting in premature motor failure. It is necessary to provide common mode and differential mode filtering to protect the motor. These magnetics also need to be foil wound to remove the proximity loss. Litz wire is not satisfactory and does not remove proximity losses.

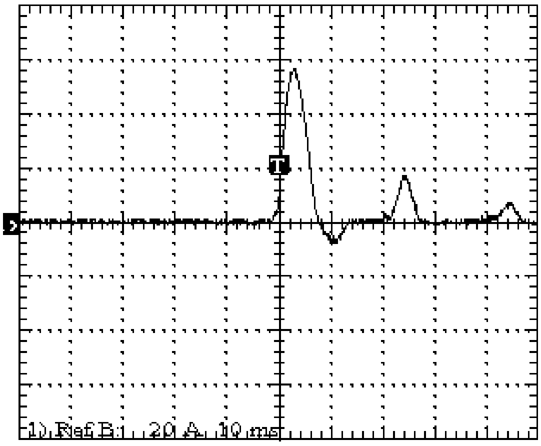
There is evidence that the huge number of voltage surges from PWM inverter output will lead to gradual deterioration and eventual failure of the insulation in low voltage (less than 1000 V) The motors most at risk are those that experience the highest magnitude surges and/or surges with the fastest rise time, since the fast rise time causes most of the voltage to be dropped across the first few turns in the winding.

There is also evidence that the fast rise time of the inverter output charges up the rotor and the only way out for the charge is eventually to discharge through the bearings of the motor and finally the bearings are destroyed. Inverters up to 30 kW designed and manufactured by Schaffler switch at 25 kHz. The output is filtered through common mode and differential mode filters.

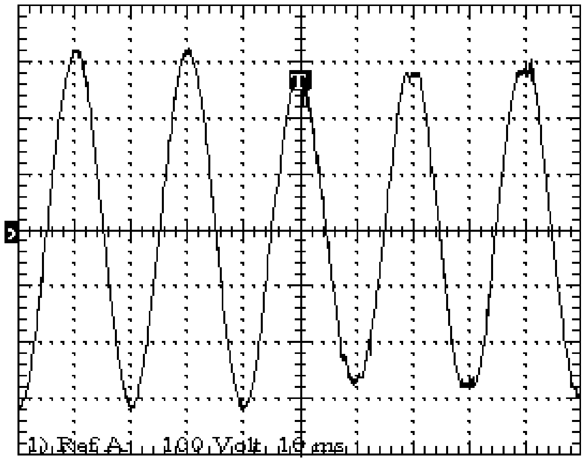
Cycle by Cycle Current Limiting (CBCCL)

This concept has been developed so that 3-phase induction motors can be Direct-On-Line (DOL) started. This is the principle that is being designed for the compressors in air conditioning systems whenever more than one motor is connected to one inverter. CBCCL enables more than one motor to be DOL started from one inverter as required.

The principle is proven and illustrated using the Schaffler single phase inverter. The following figure illustrates the function when starting a microwave oven, probably the most difficult load to start. When a microwave is connected to a domestic 240 Vac supply, the current in the first half cycle exceeds 100 amps. When supplied from an inverter with CBCCL, the current was reduced to 55 amps which was the safe current for the inverter used for the test.

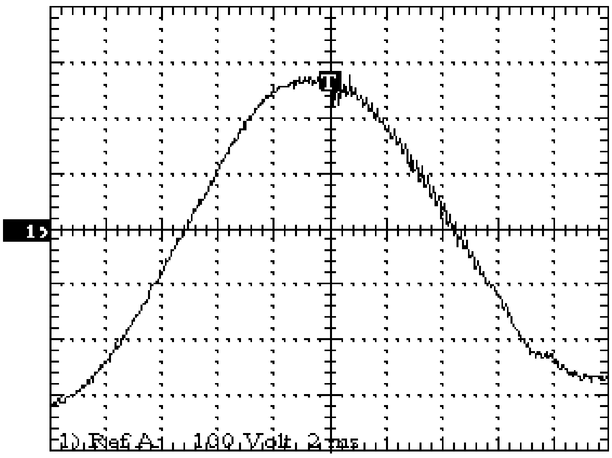


Current recording without CBCCL



Voltage recording with CBCCL

The recording below shows how the current limiting crawls up the sine wave acting at 30 kHz.



With this function applied to three phase inverters, the inverter can almost be regarded as infinite bus bars as connected to the grid.

Bernard Schaffler MSc Eng. CP Eng.

Surge and Transient Parameters

Extract from British Rail BRB/RIA12

Type of Disturbance	Voltage Level	Duration	Source Impedance
Supply related surge	3.5 x Vc	20 msec	0.2 ohms
	1.5 x Vc	1 sec	0.2 ohms
Direct Transient	800 V	100 µs	5 ohms
	1500 V	50 µs	5 ohms
	3000 V	5 µs	100 ohms
	4000 V	1 µs	100 ohms
	7000 V	0.1 µs	100 ohms
Indirect Transient	1500 V	50 µs	100 ohms
	3000 V	5 µs	100 ohms
	4000 V	1 µs	100 ohms
	7000 V	0.1 µs	100 ohms

Vc - Nominal Control System Supply Voltage