ENSURING INVERTER DRIVES DO NOT PRESENT A SIGNALLING SAFETY HAZARD - THE SOLUTION

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The essence of compatibility between any traction power electronic equipment and signalling system which share a conductive path through the running rail is based on two principles:-

i) Signalling frequency avoidance,

and only when this is impossible,

ii) Signalling frequency minimisation.

In the case of inverter propulsion drives the variable frequency nature of the equipment makes the task of ensuring compatibility more complex than for other forms of drive. The mechanism of conducted interference (other forms of interference will not be considered in this paper) is by generated harmonic currents flowing in the rails at signalling frequencies. Whilst this principle applies

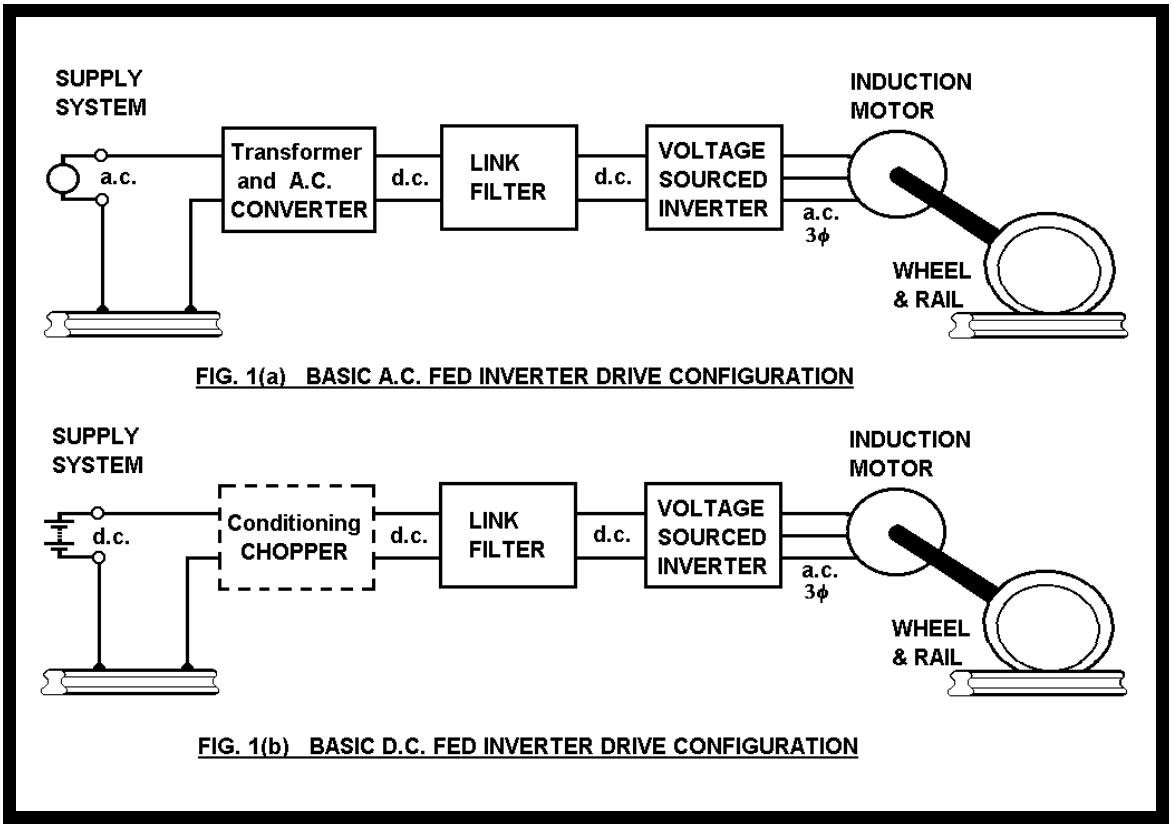

FIG. 1(a) BASIC A.C. FED INVERTER DRIVE CONFIGURATION

FIG. 1(b) BASIC D.C. FED INVERTER DRIVE CONFIGURATION

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to any form of supply feed, in practice, the different nature of a.c. and d.c. fed inverter propulsion equipments results in a different emphasis. Consequently, this paper considers a.c. and d.c. supplied equipments separately, the elementary configurations being shown in fig. 1.

The sources of harmonics are twofold:-

i) From any power conversion stage within the propulsion equipment.

ii) From the supply system.

Dealing with supply fed harmonics first, the subject of signalling frequency avoidance is outside the scope of this paper, as it does not pertain to the propulsion equipment. However, the propulsion equipment does influence the minimisation of source signalling frequencies. This is achieved by maximising the input impedance of the propulsion equipment to the relevant signalling frequencies. Clearly, if the supply system assuredly avoids the signalling frequencies, it may be an unnecessarily costly and weighty exercise to minimise these frequencies. In these circumstances it is up to the railway operator to specify realistic minimum input impedances for traction equipment. The input impedance specification is normally met in the traction equipment by design of the passive component elements that comprise the supply input stage of the equipment. In both a.c. and d.c. supplied equipments these components may also be instrumental in minimising harmonics generated from within the propulsion drive.

Now to consider harmonics generated by the power conversion stages. The first compatibility principle to apply is avoidance. To understand the techniques involved it is appropriate to consider signalling frequencies banded into 3 separate groups.

a) Power frequencies which normally lie within the operating range of the inverter(s) fundamental frequency.

Typically 0 - 200Hz.

b) Intermediate frequencies which encompass the nominal switching (carrier) frequencies for GTO inverters and converters.

Typically 200 - 1kHZ.

c) Traction Immune (TI) signalling frequencies, which lie above fundamental or carrier generated frequencies.

Typically 1KHZ - 5KHZ.

The most effective system for inverter harmonics signalling frequency avoidance is a technique referred to as harmonic elimination. This method is directly applicable to categories a) and b). Although it operates actively, it is essentially a frequency avoidance technique, unlike power circuit active filtering which reduces harmonics already present (active filters are not considered in this paper). Harmonic elimination is a pulse width modulation (PWM) strategy applied to a power electronics conversion stage, and is of great benefit to inverter control. The generation of a harmonic elimination switching strategy is mathematical[1,2], based on ideal inverter switching waveforms and three phase symmetry of the inverter, to remove low order harmonics from the voltage spectrum of the inverter output. If an inverter phase produces m chops per half cycle (fig. 2), it turns out that the maximum number of harmonics that can be eliminated is m, because m independent switching angles are present in a 0-90° waveform section, and the rest of the cycle just reflects this section. It requires the elimination of two odd harmonics on the a.c. output of the inverter to remove just one harmonic on the d.c. input side. This is because the modulation process treats the two a.c. side harmonics as sidebands of the d.c. side harmonic. Thus, the example of fig. 2 is capable of eliminating just one d.c. side harmonic.

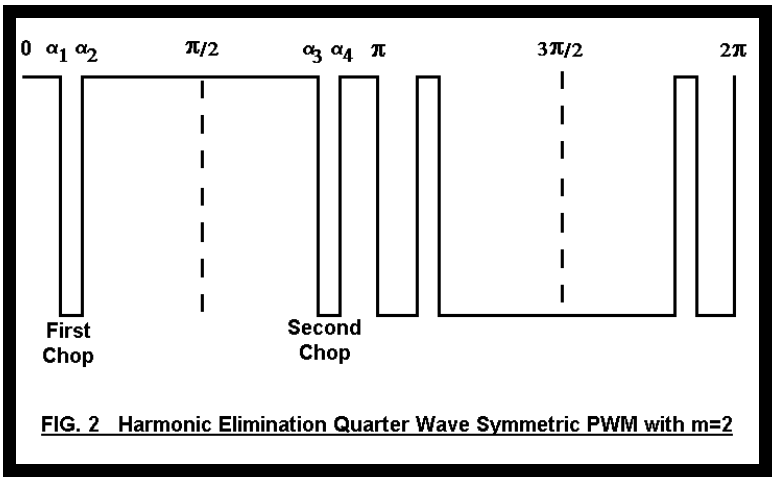

FIG. 2 Harmonic Elimination Quarter Wave Symmetric PWM with m=2

By selecting a suitable strategy at all inverter operating frequencies it becomes possible to avoid the harmonic generation at category a) and b) signalling frequencies. It should be stressed that the strategies are designed to avoid specific frequencies, and will not globally cover categories a) and b). If the signalling frequencies are changed then the harmonic elimination PWM should be redesigned. A variation on the theme of harmonic elimination is harmonic minimisation, when the low order harmonics are not eliminated but reduced to acceptably low levels. This allows scope to control higher frequency harmonics such as those in category c). However, if more than one or two category c) frequencies have to be controlled this approach is limited.

It is evident that TI frequencies can not always be avoided so minimisation becomes essential. Fortunately, the relatively high frequencies involved make power circuit filtering practical. In a d.c. fed system this is achieved by an LC line filter on the link. On 25kV a.c. supplied systems less link filtering is necessary (assuming some form of harmonic control is operated on the inverter PWM), as substantial attenuation is provided by the front end converter and transformer. Depending on specified signalling interference levels, this attenuation can make it possible for this type of equipment to employ a non harmonic elimination inverter PWM strategy, and still minimise category a) and b) frequencies adequately.

With a.c. fed systems the problem of harmonic control is dominated by the nature of the converter, whether single phase thyristor bridges or pulsed GTO converters, and techniques for interleaving multiple converters to cancel carrier harmonics. Interleaving raises the frequency of dominant harmonics to avoid category b) frequencies, but does not assist category c) where the problem is most significant. Harmonic elimination techniques on the converter can be employed to shift the dominant frequencies to a safe region.

The advantage of a voltage conditioning chopper on the front end of a d.c. fed system is that it can be arranged to transform the d.c. supply voltage to a desirable constant link voltage, for improved inverter operation. The penalty is that it adds to the spectral complexity because of the intermodulation of the chopping frequency with larger inverter harmonics. The step up chopper variant is especially suspect as it is amplifying inverter input current harmonics back to the supply, and substantial link filtering is the only recourse.

The remainder of this paper deals with the practical issue of unpredicted harmonic generation and its interference implications. It was stated earlier that harmonic elimination techniques are based on ideal inverter switching edges and three phase symmetry. Under normal operating conditions this is only an approximation, and if an inverter develops a partial fault which does not fully inhibit its operation, these are not valid assumptions. The harmonic spectrum will be distorted under these conditions, creating potential interference.

Due to the low motor resistance a switching asymmetry, from positive to negative half cycles between inverter arms, will cause significant d.c. current to flow from motor line to line. These currents cause the generation of fundamental frequency on the supply side which can be a problem to category a) signalling frequencies. Other consequences of asymmetry is the emergence of otherwise cancelled triplen harmonics if quarter wave symmetry is lost, and the appearance of even or otherwise eliminated odd harmonics. Finally, asymmetry in either the inverter output or the induction motor can induce frame currents in the motor, caused by unbalanced motor currents. If the motor frames are grounded then these currents may find their way into the return rails. Diagrams illustrating the possible current paths of unwanted harmonics will be given in the presentation, alluding to the necessary positioning of a fail safe monitor, or other means of ensuring safe operation.

References.

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2. Novel Algorithm for Generating near Optimal PWM Waveforms for A.C. Traction Drives, Taufiq J.A, Prof. Mellitt B. and Goodman C.J. IEE Proc, Vol. 133, Part B, No. 2, March 1986.