FUSE UNEXPECTED OPERATIONS IN SOFT-STARTERS BY DISSIMILAR CURRENT DISTRIBUTION

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Abstract:
At present time, the application of low and medium voltage soft-starters (permanent or only during the start) and motor drives is wide spread in the industrial systems, being most of these motors short-circuit protected by fuses.
The power electronics introduces harmonics in the current and voltage waves, between them the most important are the 5° and 7°, being measured values of THD as high as 30 %.
Besides, when soft-starters are protected by fuses, the specific energy of the assisted start current is several times the direct start value, being measured ratios between 10 and 20, with starting times of 15 seconds and less than a second respectively.
After the report of several of these fuses bad or unexpected operations, a study was done about the normal load behaviour of commercial fuses under 400 Hz and 1200 Hz supply. The frequency was adopted for the equipment availability, because this is one of the standards for mainframes and aircraft supply, and the second one due to the importance of 20° and 24° harmonic in the driver current waves.
The high-speed fuses normally have several parallel ribbons, regularly distributed inside the fuse body, for which the experimental approach consisted in the determination of the current distribution between the several ribbons and its comparison when connected to 50 HZ, 400 Hz and 1200 Hz. In order to avoid any constructive alteration, the current distribution was obtained for the voltage drop in each fuse element.
The behaviour under 50 Hz conditions is very symmetrical, in magnitude and phase, except by the extremely small constructive differences. Under 400 Hz. and 1200 Hz., the behaviour is dissimilar, being measured amplitude differences of 20 % and phase shifts of 20 ° in average.
Besides, it is necessary carry out a carefully study of the fuse position (inside the starter) in order to take account of the proximity effect, being that matter the objective of further study.
From the preliminary results, the dissimilar current distribution can be the cause of the fuses mal-operation, being necessary the fuse derating in order to avoid the ageing and premature melting.

Keywords: electric fuses, harmonics, current distribution, skin effect

1- INTRODUCTION

The advances in the power electronics, microprocessors and magnetic materials of the last 20 years have made possible to get significant advances in the application of induction motor drivers and soft-starters. With these new technologies a notable increment has taken place in the field of application of this type of motors overcoming in many cases, as much in cost as in benefits to the traditional d.c. motor.
With the new second generation electronic switches it has become possible to build commercially attractive electronic inverters which can operate with frequencies bigger than 10 kHz [1]. For these values of commutation frequency inverters are built with pulse wide modulation (PWM) being used in the great majority of the variable frequency converters applied to induction motors.
This type of drive consists of a rectifier with not controlled diodes in the input; a filter formed by a big capacitor so that the rectifier entrance appears like a voltage source with a very small internal impedance; and a inverter having electronic switches (usually IGBT transistors) that allows to control as much the magnitude as the frequency of the exit tension. The input alternating current of

the frequency changer contains a great quantity of harmonic, with a high percentage of fifth one as can be observed in figure 1, situation which is also presented in the start of motors with soft starters, as shown in figures 2.

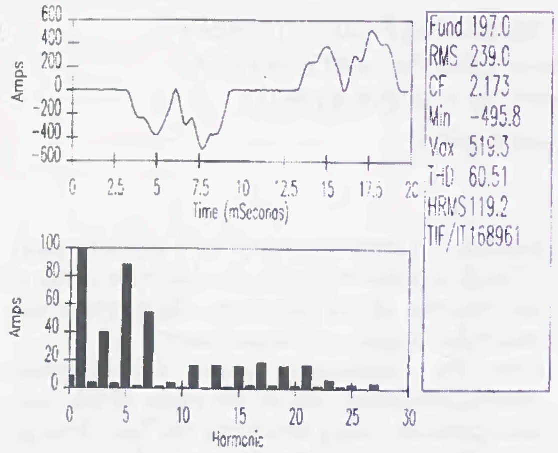


Fig. 1, Steady state current of a 150 HP, 380 V motor drives.

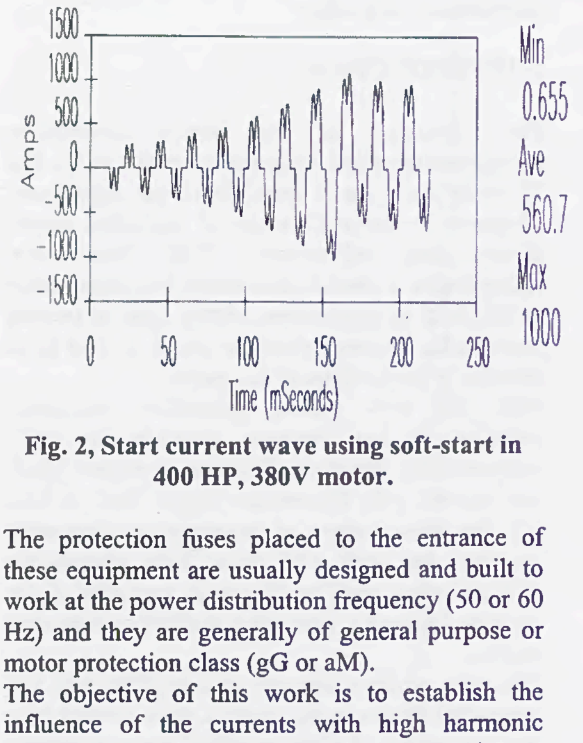


Fig. 2, Start current wave using soft-start in 400 HP, 380V motor.

The protection fuses placed to the entrance of these equipment are usually designed and built to work at the power distribution frequency (50 or 60 Hz) and they are generally of general purpose or motor protection class (gG or aM).

The objective of this work is to establish the influence of the currents with high harmonic content in the behaviour of the industrial type fuse.

2- THEORETICAL ANALYSIS

The phenomenon that can affect the behaviour of a fuse with different values of frequencies are the established ones for the electromagnetic laws. If we consider that a fuse is compound for an or more parallel ribbons, with a current distribution among the different ribbons as well as to the wide of each one of them that depends on its resistance and inductance. It is then concluded that the dependence of this distribution with the frequency is precisely due to the inductance.

If we study what happens in a fusible ribbon when it is travelled by currents of different frequencies, it is clear that the distribution of the current flow in the cross section will depend on the frequency according to that postulated by the well-known phenomenon of skin effect. The skin effect postulates that for high frequencies the current distribution in the conductor cross section is confined to its surface, causing that the effective resistance of the conductor increases as the frequency does. In the references a study is presented that concludes that the influence of the effect skin in thin ribbons as the used as fuse elements, for frequencies smaller than 5 kHz, is worthless in the depth and it can be important in the width. [2]

In the case of having ribbons in parallel, the distribution of the currents would not only depend on its resistances and own inductances but rather the effect caused by the magnetic flux. Which is created by one ribbon on the other ones, inducting stray currents that will also affect the current distribution. This phenomenon that depends on the distance among ribbon conductors denominates proximity effect. In the references a study of the influence of the frequency in the current distribution among three parallel ribbons with frequencies between 0 and 100 kHz was carried out. [2]

3- EFFECT OF THE HARMONIC CONTENTS ON INDUSTRIAL FUSES

Although of the theoretical analysis and of that concluded by other authors in the consulted bibliography it comes off that the high frequencies have an important effect in the current distribution among parallel fuse elements. In the authors' knowledge there is not any investigations on the influence of these phenomenon in industrial fuses with frequencies of the order of the harmonics presented in variable speed motor drivers and soft starters. [3].

For such a reason was carried out an experimental study using fuses available in the market and also on fuse prototypes to evaluate the influence of some parameters like the ribbons separation and width of the same ones.

4- DESCRIPTION OF THE TEST SERIES.

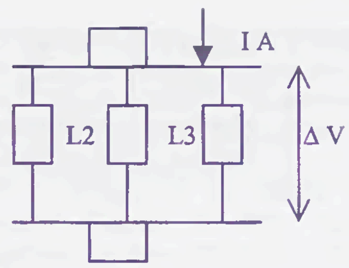
The way to observe the effect of the frequency on the current distribution consisted on to measure the voltage drops in the similar fuse elements and to quantify the difference among the measurements at different frequencies. The power on 50 Hz was took directly from the main supply, using a variable autotransformer in order to allow the current regulation. The currents in 400 and 1200 Hz were took from two synchronous generator. The voltage measurements were made in direct form, on the other hand the current was measured with an amperometer clip, carrying out the transmission by optic fibres (in order to become independent of the reference earth), having previously tuned the offset aim to avoid phase errors. As the used digital oscilloscope possesses 4 input channels, they registered simultaneously the three voltage signals corresponding to each one of the parallel fuse elements and the indication of the total current.

The selected samples were following VDE 0636 standard, size 3, ceramic body, iron lids and with three copper fuse elements. Part of them were commercial devices, being the remaining ones assembled in the own workshop using commercial fuse element sheets whose separation was of about 5 mm. [4]

The measurements were made after having lapsed a time of the order of the 30 minutes, in order to allow the thermal stabilisation of the under test device.

The fuse physical position as also the remaining test conditions (circuit, ambient, etc.), were maintained exactly the same in all the tests.

The figure 3, shown the fuse element positions and the corresponding connections.



-Chanel 1: fuse element 1 voltage drop signal (L1) in mV.
-Chanel 2: fuse element 2 voltage drop signal (L2) in mV.
-Chanel 3: fuse element 3 voltage drop signal (L3) in mV.
-Chanel 4: signal of the total current (I) in mV.

Fig. 3

It should not be forget that cannot be guarantee an exact geometric distribution of the ribbons inside the fuse body in the commercial fuses, since although it is certain that the devices were dismantled in order to weld on them the signal conductors, the position of the sheets was not altered.

The width of the sheet was modified from test to test, using elements with several bridges, between 2 and 7.

5- RESULTS

The obtained results of voltage drop on the ribbons denominated L1, L2 and L3, jointly with the total current and their absolute and percentile differences, they are indicated in the Tables I and II.

Table I, commercial fuses.

Test Nº	Notes	f (Hz)	L1	L2	L3	L1-L2	L2-L3	L1-L3
1	Sample 1	50	12,7	13,36	12,62	-0,66	0,74	0,08
	In= 400 A	400	15,25	13,36	12,62	1,89	0,74	2,63
	6 bridges	difference	2,55	0	0	-2,55	0	-2,55
	I=128 A	% difference	**20,08**	**0,00**	**0,00**			
2	Sample 2	50	22,65	24,8	21	-2,15	3,8	1,65
	In= 400 A	400	20,7	32	23,75	-11,3	8,25	-3,05
	6 bridges	difference	-1,95	7,2	2,75	9,15	-4,45	4,7
	I=226 A	% difference	**-8,61**	**29,03**	**13,10**			

3	Sample 3	50	38,94	40,9	39,36	-1,96	1,54	-0,42
	In= 400 A	1200	39,22	46,34	48,54	-7,12	-2,2	-9,32
	6 bridges	difference	0,28	5,44	9,18	5,16	3,74	8,9
	I=300 A	% difference	**0,72**	**13,30**	**23,32**			

Table II, assembled fuses.

Test N°	Notes	f (Hz)	L1	L2	L3	L1-L2	L2-L3	L1-L3
4	assembled	50	37,32	36,31	37,81	1,01	-1,5	-0,49
	2 bridges	1200	39,6	38,77	37,96	0,83	0,81	1,64
	I=107 A	difference	2,28	2,46	0,15	0,18	-2,31	-2,13
		% difference	**6,11**	**6,77**	**0,40**			
5	assembled	50	80,725	79,23	78,945	1,495	0,285	1,78
	3 bridges	1200	90,58	89,425	83,89	1,155	5,535	6,69
	I=280 A	difference	9,855	10,195	4,945	0,34		
		% difference	**12,21**	**12,87**	**6,26**			
6	assembled	50	43,35	35,64	38,289	7,71	-2,649	5,061
	5 bridges	1200	53,543	41,8	47,95	11,743	-6,15	5,593
	I=288 A	difference	10,193	6,16	9,661	-4,033	3,501	-0,532
		% difference	**23,51**	**17,28**	**25,23**			
7	assembled	50	24,65	21,57	23,972	3,08	-2,402	0,678
	7 bridges	1200	34,2	31,835	29,47	2,365	2,365	4,73
	I=282 A	difference	9,55	10,265	5,498	0,715	-4,767	-4,052
		% difference	**38,74**	**47,59**	**22,94**			

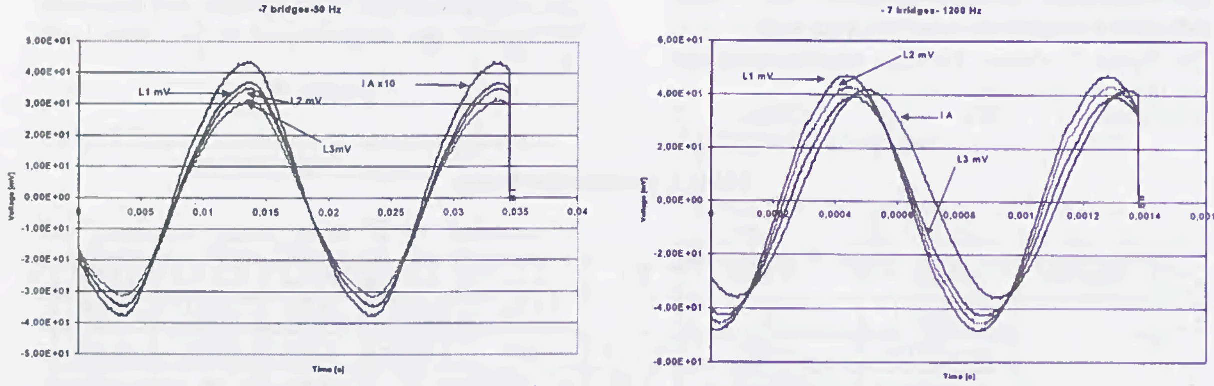


Fig. 4

The figure 4 shows the oscillograms of the voltage drops in the three ribbons and the total current of the test 7; having a number of bridges of 7, with frequencies of 50 Hz. and 1200 Hz., where it is shown the unequal current distribution and the phase shifts.

6- CONCLUSIONS

Of the reduced number of determinations, it can be inferred that for the existent frequencies in motor drivers and soft-starters of industrial systems (50 or 60

Hz.), the asymmetry in the voltage drops indicates an unequal current distribution. Such an effect produces bigger losses and operation outside of the fuse range. This problem justifies bigger study, being the present work only a provisional contribution in such a direction.

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