CONTACTOR IMMUNITY RELATED TO VOLTAGE SAGS

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ABSTRACT

Voltage sags are among the most important power quality events due to their economic effect on all types of customers, especially industrial users. Normal contactors would open when a voltage sag – of given depth, duration, phase-jump and starting angle – takes place. The paper shows the results obtained from a series of experimental tests carried out on six contactors of dissimilar characteristics and manufacturers. The six traditional immunity curves (or time/voltage characteristics) were obtained, with two more variables to be included later. The tested contactors show similar behavior, with very small variations. Besides, a few tests were conducted to analyze the increase in contacts voltage-drop due to voltage sag presence, in order to investigate the contacts welding possibility under rated-current conditions. Complete information related to contactor immunity need to be given in three-dimension or two-dimension graphical format.

INTRODUCTION

The probability of voltage sag occurrence is nearly four times higher than that of the short interruption. Customer complaints related to voltage sags represent approximately 80 % of all the complaints due to power quality transients. Industrial losses due to voltage sags can be reduced if motors are kept connected, as far as possible from the process point of view [1]. The normal device used for motor connections and disconnections is the contactor, thus it is of importance to know what type of voltage sags will open the AC contactor or leave it closed. This information is very valuable not only to the contactor user but also to the designer and manufacturer.

In spite of their robustness as electromagnetic devices, contactors must be considered as “sensitive equipment” when studied from the voltage-sag immunity viewpoint, probably being opened when the supply voltage drops to an average of 70 % for more than 1 or 2 cycles [1]. Equipment in general are considered sensitive when they drop out easily due to power quality events; in this case the contactor opens when submitted to short and shallow voltage sags. Sensitive equipment immunity against voltage sags is normally expressed in graphical form using a voltage magnitude/duration chart. For most cases the immunity is completely defined by these two variables, which means that the voltage sag is assumed rectangular. For contactor immunity characterization another variable must be considered, that is the voltage-sag starting angle. The most critical angle for dropout is around voltage zero crossing, where a voltage drop to between 70 and 80 % of the rated voltage is enough to cause contactor opening. For starting angle near the peak voltage, the magnitude for contactor opening drops to nearly 50 % [2]. A three-dimensional graph, considering voltage-sag magnitude, duration, and starting angle was presented. The effect of phase-jump angle on the voltage-sag immunity has not been investigated before. In order to include this new variable (phase-jump angle) in the analysis, an experimental test circuit was assembled, with which the four voltage-sag variables can be independently modified.

The methodology presented here is exclusively experimental. The analysis of contactor behavior using purely analytical approaches has been reported elsewhere [3, 4]. Six contactors of different types, from three manufacturers, were tested. The types were selected due to their wide-spread application in the Argentinean industrial circuits. The phase-jump angle was selected based on previously recorded values of voltage sags produced by faults located in medium-voltage systems [5]. The voltage magnitude was changed in 5% steps, and the making angle was varied in 10° steps. As the dropout time was searched, the voltage-sag duration was mostly fixed at its maximum value.

RESULTS

More than 300 tests were carried out in order to verify the general trend of contactors; only a few are shown here mostly in graphical form. The three contactor brands tested are denoted as brands A, B, and C.

Figure 1 shows the opening time of a brand A type 1 contactor when submitted to voltage sags of variable starting angle for three different magnitudes, 50, 55 and 60 %, without phase-jump. The maximum value on the vertical axis was selected to be 30 ms, based on the maximum

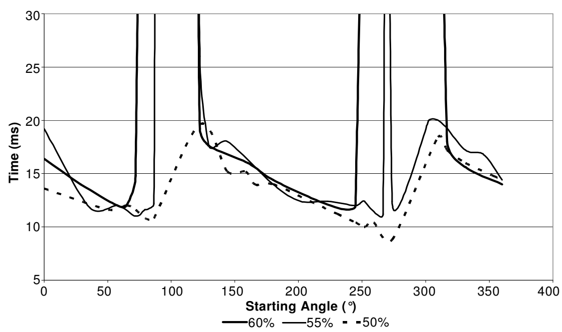

Figure 1 Brand A type 1 contactor opening time vs. starting angle without phase-jump.

recorded opening time; thus the asymptotic lines (nearly vertical) around 90° and 270° indicate infinite opening time, which means the contactor remains closed. It can be seen that an increase in the disengagement time – as the voltage magnitude rises – reaches a situation where the device does not open for higher voltage magnitudes, but only for starting angles near 90° and 270°. In other words, the device remains closed when starting angle is close to the voltage peak values.

Figure 2 shows the behavior of the same contactor of Figure 1, but with a phase-jump angle of 45°. It can be noted that the behavior is now different. In order to clarify the discrepancy in the contactor behavior, Figure 3 shows the opening time as a function of starting angle for a magnitude of 50 % with and without 50° phase-jump. It is a border situation, because with phase-jump and for a starting angle of 90° the device under test opens in 24 ms, while for an angle of 270°, the contactor remains engaged. The contractor behavior without phase-jump maintains the same curve shape, opening in a shorter time (3.5 ms) irrespective of the starting angle. In this case the existence of phase-jump angle slightly improves the contactor behavior, especially for starting angles around 270°.

In order to point out the border situation of the previous graph, Figure 4 shows the dissimilar behavior when the voltage sag magnitude is increased to 55%, a situation where the contactor kept closed for the angles corresponding to the peak voltage (90° and 270°), irrespective of having a phase-jump. The opening delay between the two lines is smaller than the previous case but still clearly noticeable, even though in this case the phase-jump angle was 47°. The general contactor behavior is better with phase-jump except for starting angles close to positive maximum voltage values.

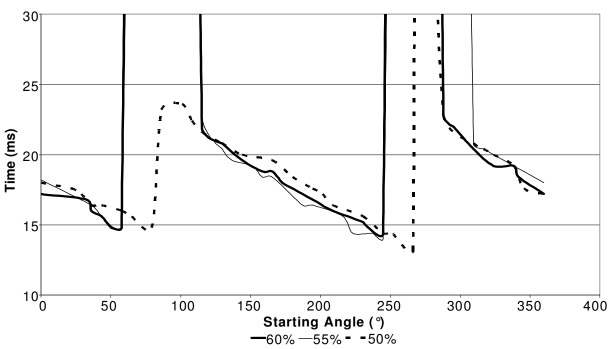

Figure 2 Brand A type 1 contactor opening time vs. starting angle with 45° phase-jump angle.

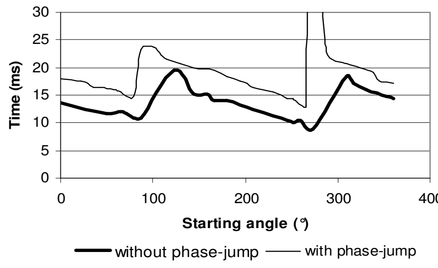

Figure 3 Brand A type 1 contactor with and without 50° phase-jump angle.

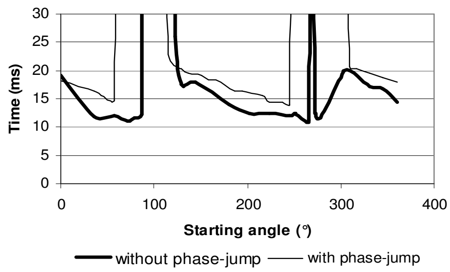

Figure 4 Brand A type 1 contactor with and without 47° phase-jump angle.

Figure 5 shows the results for the same contactor type, but for a voltage magnitude of 60 %. The curve shape is similar; however the range of switching angle around voltage peaks – for which the device did not open – is wider. Similar to the previous situation, the general behavior is improved, except for angles in the regions of maximum voltage where the presence of phase-jump disengages the contactor, otherwise it would remain closed.

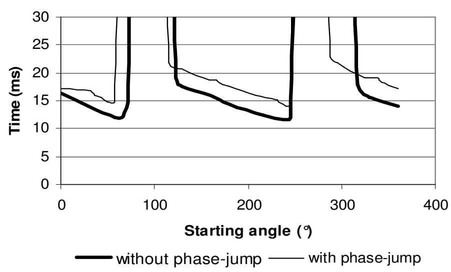

Figure 5 Brand A type 1 contactor with and without 50° phase-jump angle.

For comparative purpose Figure 6 – similar to Figure 2 but for another contactor brand and type (denoted by B and 3) – is given, for voltage sag magnitude of 40, 45 and 50 %, and a phase-jump angle of 52°. An extremely long delay in opening can be seen, in comparison with the previously recorded values, reaching 95 ms for a starting angle of 90°. Figure 6 shows – for voltage magnitude of 45% – a significant variation in contactor disengagement time around 90°, jumping from nearly 22 ms to 95 ms. Opening times of 95 and 22 ms are illustrated in Figures 7 and 8, respectively, showing the time discontinuity, which can be deduced from the coil voltages and currents. The phase-jump is clearly noticeable in both figures.

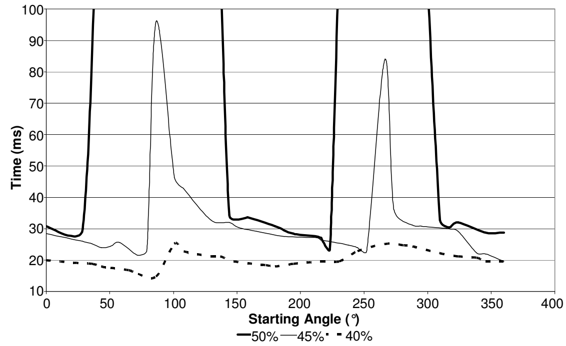

Figure 6 Brand B type 3 contactor opening time vs. starting angle with phase-jump of 52°.

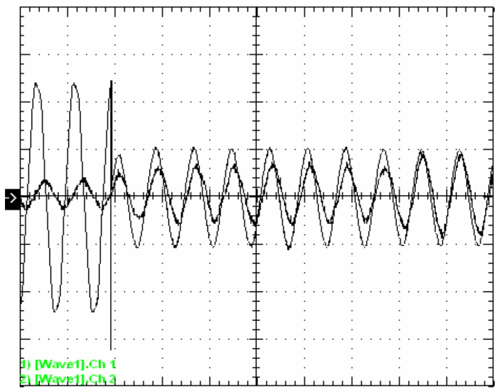

Figure 7 Voltage and current waveforms showing brand B type 3 contactor delayed opening, for magnitude of 45%, starting angle of 86°, and phase-jump angle of 52°.

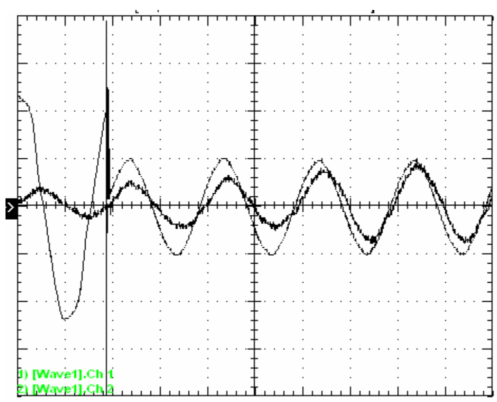

Figure 8 Voltage and current waveforms showing fast opening of brand B type 3 contactor, for magnitude of 45%, starting angle of 79°, and phase-jump angle of 52°.

Figure 9 shows the behavior of brand B type 3 contactor for voltage magnitude of 45%, and starting angle of 79° without phase-jump. It can be seen that the contacts remain closed, showing a better behavior than with the presence of phase-jump angle. Figure 10 (similar to Figure 3, but for contactor brand B type 3, for voltage magnitude of 40 % and phase-jump of 0° and 52°) shows similar opening delay of

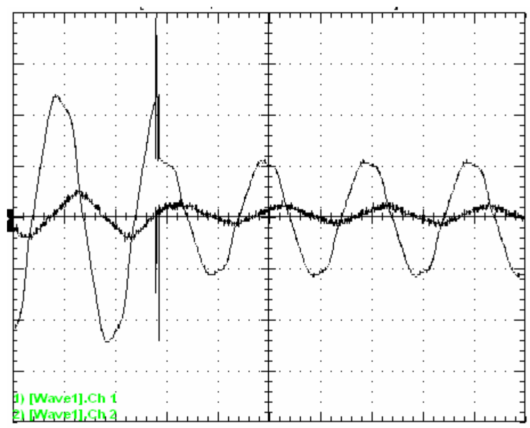

Figure 9 Voltage and current waveforms showing brand B type 3 contactor closed, for magnitude of 45%, starting angle of 79°, and without phase-jump angle.

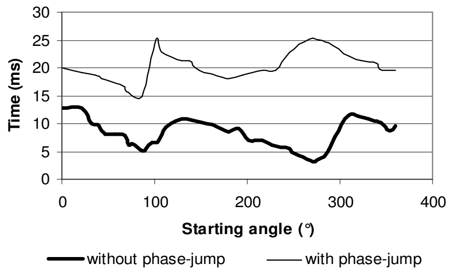

Figure 10 Brand B type 3 contactor, voltage magnitude 40 % with and without 52° phase-jump angle.

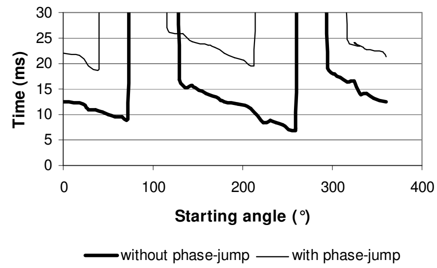

Figure 11 Brand C type 2 contactor, voltage magnitude 45% with and without 47° phase-jump angle.

approximately 10 ms. Figure 11 (similar to Figures 3 and 10, but for contactor brand C type 2) shows the same behavior for voltage magnitude of 45 % and phase-jump of 0° and 47°.

The behavior of the three contactor brands and types is very similar, showing a general trend. Results relating voltage sag magnitude and starting angle are in good agreement with previously published experiments, when minimum voltage magnitude for keeping the contactor closed is plotted as a function of starting angle. The only difference in this case is having magnitude values for a starting-angle range from 0° to 360° instead of 0° to 180°, as shown in Figure 12 [2]. It was also experimentally verified the particular effect of the shading-ring coil on contactor behavior which – at both 0° and 47° phase-jump angles – kept the contactor closed for extremely short interruptions or deep voltage sags, as has been indicated where phase-jump angles were not considered [2].

CONCLUSIONS

The following conclusions can be drawn from the experimental results:

- For all the tested contactors, with zero phase-jump angle, the opening took place before 30 ms.
- Phase-jump angle affects the contactors by delaying the dropout time, reaching a maximum delay of 100 ms.
- The presence of a phase-jump angle of approximately 50° widened the range of voltage-sag starting angles for which the contactor remains closed.
- There are cases where the presence of a high phase-jump angle prevents the contactor opening.
- The six tested contactors have shown similar behavior.
- The worst conditions are zero starting angle and zero phase-jump angle.
- AC contactor immunity curves for the worst conditions become a pair of coordinates that identify the voltage-sag magnitude for equipment dropout.

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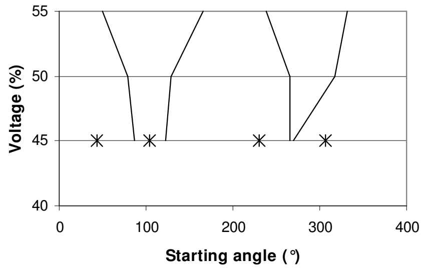

Figure 12 Brand C type 2 contactor voltage sag magnitude vs. starting angle for contactor opening with phase-jump angle (*) and without phase-jump angle (solid line).

REFERENCES

[1] T. S. Key, 1995, "Predicting behavior of induction motors during service faults and interruptions," *IEEE Ind. App. Mag.,* vol. 1, no. 1, 6-11,

[2] E. R. Collins, M. A. Bridgwood, 1993, "The impact of power system disturbances on AC-coil contactors," *IEEE Textile, Fiber, and Film Ind. Tech. Conf.,* Greenville, USA, 1-6.

[3] J. Pedra, F. Corcoles, and L. Sainz, 2002, "Study of AC contactors during voltage sags," *Int. Conf. on Harmonics and Quality of Power*, Rio de Janeiro, Brazil, vol. 2, 565-570.

[4] H. Mohamad, K. Mohamed Nor, 2004, "Evaluation on sensitivity of ac contactors during voltage sags," *IEEE Region 10 Conf., TENCON*, Chiang Mai, Thailand, vol. 3, 295 - 298.

[5] M. H. J. Bollen, 2000, *Understanding Power Quality Problems: Voltage Sags and Interruptions*, IEEE Press, New York, USA.