THE CONTRIBUTION OF CURRENT-LIMITING FUSES TO POWER QUALITY IMPROVEMENT

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Abstract: Voltage sags caused by power-system faults can cause serious problems for computer systems, adjustable-speed drives and other industrial and domestic equipment. The effect of a voltage sag depends on its magnitude and duration. The use of current-limiting fuses for system protection reduces the duration of voltage sags, without producing excessive overvoltages, thus improving power quality.

Keywords: power quality, current-limiting fuses

1. Introduction

Ideally an electric utility should provide an a.c. supply with a voltage of constant magnitude and frequency and a perfect sinusoidal waveshape. The term "power quality" is essentially voltage quality [1], and the ITIC curve shown in Fig. 1 is widely used to define the maximum voltage deviations which are acceptable, as a function of time. Note that the shorter the time, the greater the voltage deviations which are allowed.

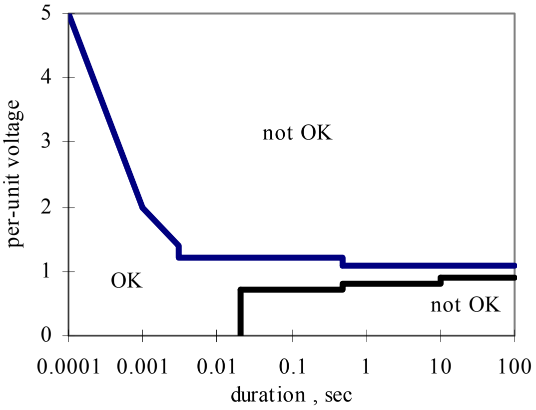

Fig.1 ITIC curve

The ITIC (Information Technology Industry Council, formerly CBEMA) curve was originally developed for mainframe computer systems, and strictly applies only to 120V equipment subject to very specific types of voltage deviations. Similar curves can be found for other types of equipment such as UPSs [2], but in the absence of an alternative the ITIC curve has become a *de facto* standard for all types of equipment and power systems.

Voltage sags (or dips) are mostly caused by motor starting, magnetizing inrush currents, or short-circuit faults, (which give the most severe sags [3]). If an event occurs which causes a voltage/time point to fall below the lower curve in Fig. 1, it is presumed that malfunction of parallel-connected equipment such as computers, adjustable-speed drives and control systems can occur. The sensitivity of this type of equipment and the associated cost of downtime has been a major factor in the increasing importance of power quality studies in recent years. It has also led to the development of equipment such as uninterruptible power supplies, dynamic voltage restorers, constant-voltage transformers and static transfer switches to mitigate the effects of voltage sags.

The upper curve in Fig. 1 represents overvoltage limits, dictated by malfunctions such as operation of overvoltage trips, insulation failure and over-stressing. Sustained overvoltages (voltage swell) of +10% are allowable for times greater than 0.5s. Short-duration transients are usually caused by capacitor switching or lightning. There is some uncertainty about the short-time overvoltage curve. In the field many overvoltage spikes above the withstand curve which caused no problems have been observed [4]. There is also debate about how the curve should be interpreted for short-duration non-sinusoidal voltages and how the per-unit magnitude should be defined [1].

2. Current-limiting protection

The ITIC curve shows that for a bolted short-circuit fault (zero voltage) the fault must be cleared in less than 0.02s. This requires fast-acting protection, and in [4] it was pointed out that current-limiting fuses can meet this requirement at low cost, except in very rare cases where the supply system is weak and the short-circuit current is too low to cause the fuse to operate in current-limiting mode [4,9].

When a current-limiting fuse clears a short-circuit fault there is a system voltage sag during the fuse prearcing time followed by a voltage rise during the arcing time, and there was some initial concern that the high arc voltage generated by the fuse could be higher than permitted by the ITIC curve. However, calculations for a typical UL class J fuse showed that the highest peak arc voltages remained within ITIC limits [4].

This has been confirmed by field tests on a radial 7.2 kV residential system subjected to single-phase short-circuit faults at various locations [5,8]. Measured voltage dips lasted only for about 2ms and the maximum voltage rises were about 1.7 p.u., both within the ITIC limits. ATP simulations using a resistance-time fuse model gave similar results.

It was also concluded in [5] that current-limiting fuses mitigated the voltage sag better than expulsion fuses, and caused less disturbance to parallel-connected loads, because the fuse arc voltage supports the system voltage, promoting recovery. In addition the current-limiting fuses provided their expected limitation of peak current and I^2t.

3. Example

The system shown in Fig. 2 will be used to illustrate in detail the voltage sags, voltage rises, effects on parallel loads, and limitation of energy provided by current-limiting and non-current-limiting protection.

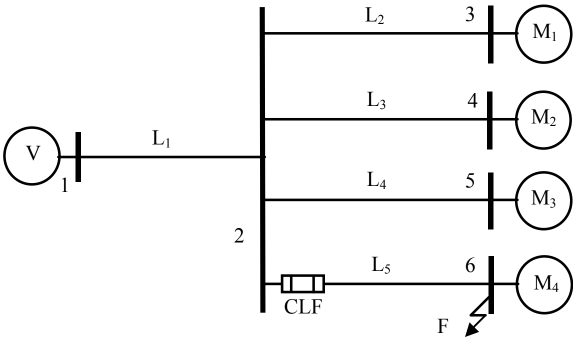

Fig.2 Motor control centre

The system of Fig. 2 has been discussed previously [6]. In this paper we will look at the behaviour in more detail. It represents a typical motor control centre with 2 smaller motors (M_1 and M_2) and 2 larger motors (M_3 and M_4). For a fault at bus 6, (on the terminals of M_4), bus 2 is the "point of common coupling" (PCC), as far as the other parallel-connected motor loads are concerned.

3.1 With current-limiting fuse protection

Fig. A.1 shows the system transients over a 0.1s period surrounding a 3-phase-to-ground short-circuit fault at bus 6, with M_1 and M_3 initially lightly loaded and M_2 and M_4 fully loaded, when protected by current-limiting fuses rated at 150% of the motor full-load current. The fault is cleared by operation of the 3 fuses in line 5. These results were computed using the method described in [7], which uses standard fuse models and takes into account 3-phase effects in the operation of the fuses as well as motor electrical and mechanical transients.

When the fault occurs the voltage at the point of common coupling (bus 2) sags to a low level, but only for a few milliseconds, until the fuses melt. In the cases shown the melting times are 9.2,5.2 and 3.3ms, so the sag duration is well within the ITIC undervoltage curve shown in Fig.1. After the fuses switch to the arcing mode the bus voltage is raised due to the appearance of the fuse arc voltages, and the fault currents in the three phases are forced to zero. The highest peak current in line 5 is 13.7 p.u.

The waveshape of the voltage transients produced during fuse operation is non-standard as far as the ITIC curve is concerned, but if we approximate them as half-sine waves of medium frequency they correspond to r.m.s. values of 1.45, 1.53 and 1.34 per-unit with durations of 2.5, 3.4 and 1.34 milliseconds. These points are close to the upper ITIC curve, but do not pose any significant problem.

After the current has been interrupted the voltages at the PCC recover to their normal values very quickly.

The raising of the bus voltage during the fuse arcing phase aids the re-acceleration of the parallel-connected motors. In effect the high resistance of the fuses in the arcing mode diverts the supply current into the parallel paths.

If the fault had been at the terminals of one of the smaller motors, M_1 or M_2, clearance of the fault by the corresponding (smaller) fuses would be faster still, with even less disturbance to the system..

3.2 With non-current-limiting protection

Fig. A.2 shows the computed interruption transients for the system of Fig. 2 if the current-limiting fuses are replaced by non-current-limiting devices which produce negligible arc voltage and which take about 2½ cycles to clear the fault. The high peak after the first quarter-cycle is composed of the fault current from the source via line 1 plus contributions from all the parallel-connected motors. There is no current limitation, which gives higher thermal and electromagnetic stresses on the circuit components. The peak network current is 21 p.u. while the I^2t let through after the fault is cleared is almost 10 times higher than if the circuit were protected by the fuses.

In this case the voltages at bus 2 sag to about 0.15-0.22 per-unit for 41-46 milliseconds, which is well in the lower region of unacceptable power quality shown in Fig. 1. However bus 2 voltage remains depressed even after the fault has been cleared. It increases slowly from about 0.6 per-unit and remains below the ITIC curve for a considerable time. The reason for this is that the speed of the parallel-connected motors drops significantly during the long-duration voltage sag. After the fault is removed all the parallel motors re-accelerate, drawing a high current from the supply, which causes the duration of the voltage sag at bus 2 to be further extended.

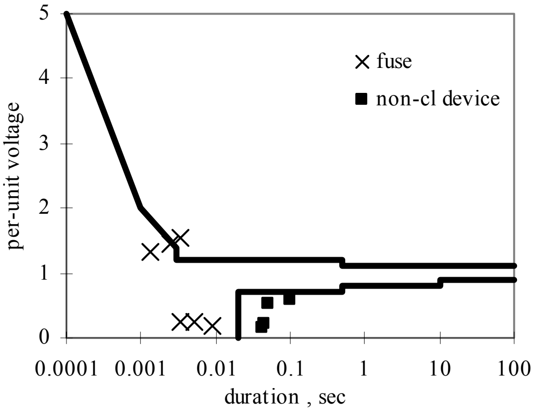

Fig. 3 Sags and peaks for the system of Fig. 2

Fig. 3 shows how these results relate to the ITIC curve. For each data point an approximate r.m.s. value of voltage has been plotted for the corresponding time duration. With current-limiting fuses the voltage sags are within ITIC limits, but with non-current-limiting protection this is not the case.

4. Conclusion

Current-limiting fuses provide protection against disruptive heating and electromagnetic effects, but also make an important contribution to the improvement of power quality. They achieve this by operating within one half-cycle, to limit the duration of voltage sags, and without producing unacceptably high voltages.

The resulting short duration of the disturbance to the system avoids further depression of voltages due to motor re-acceleration and other load effects.

Using fuses to improve the power quality of a power system is also a very inexpensive option. For systems where the cost of installing dynamic voltage restorers and similar types of equipment cannot be justified, high-speed protection by current-limiting fuses is very economical way of mitigating the effects of voltage sags.

In low and medium voltage industrial, commercial and residential network, current-limiting fuses have been improving power quality for more than 60 years, long before power quality became an important issue.

5. References

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6. Appendix

Figs A.1 and A.2 on the following pages show the transient responses computed for Fig. 2.

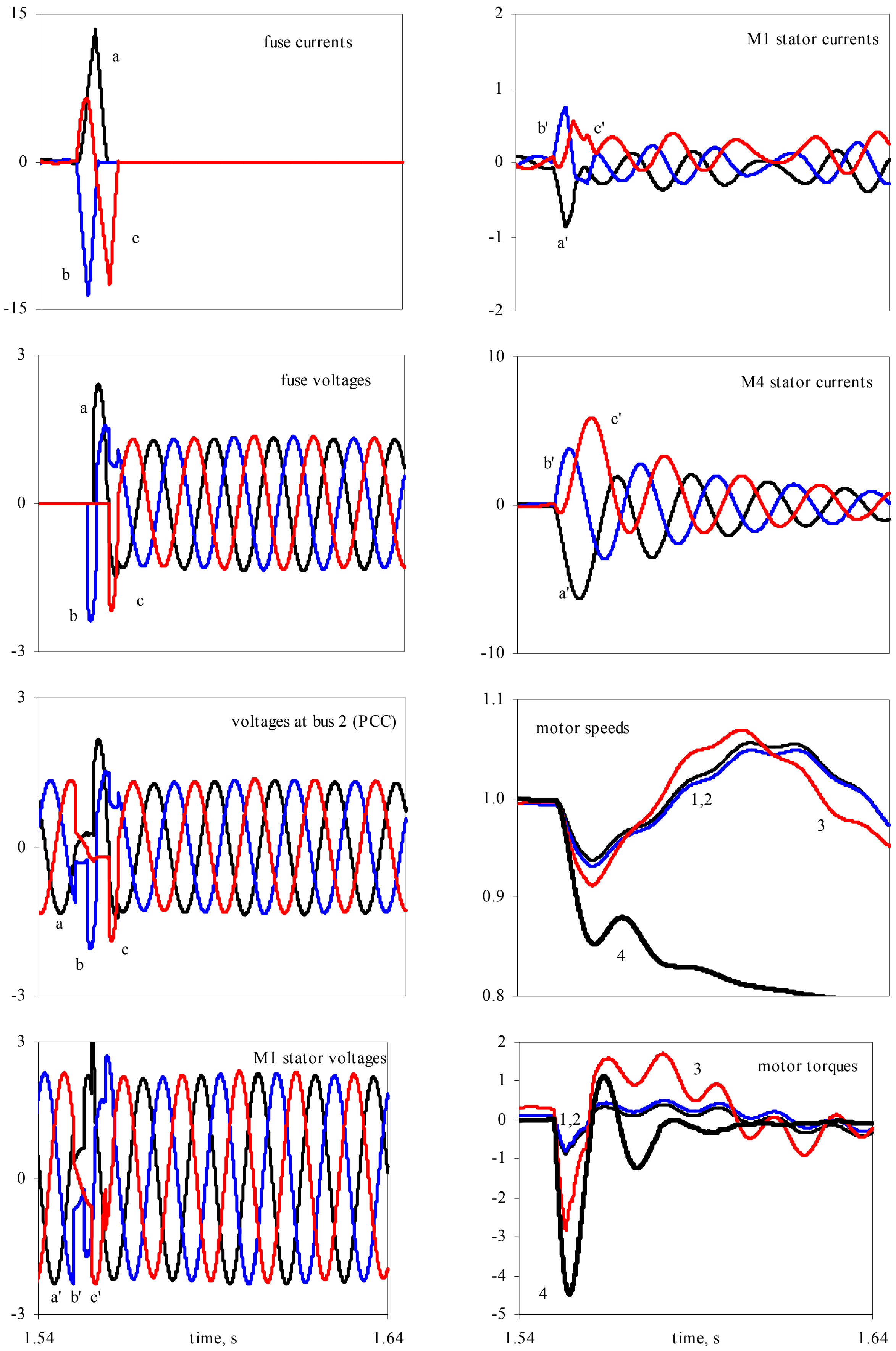

Fig. A.1 Transients with C-L protection

(all y-axis values are per-unit)

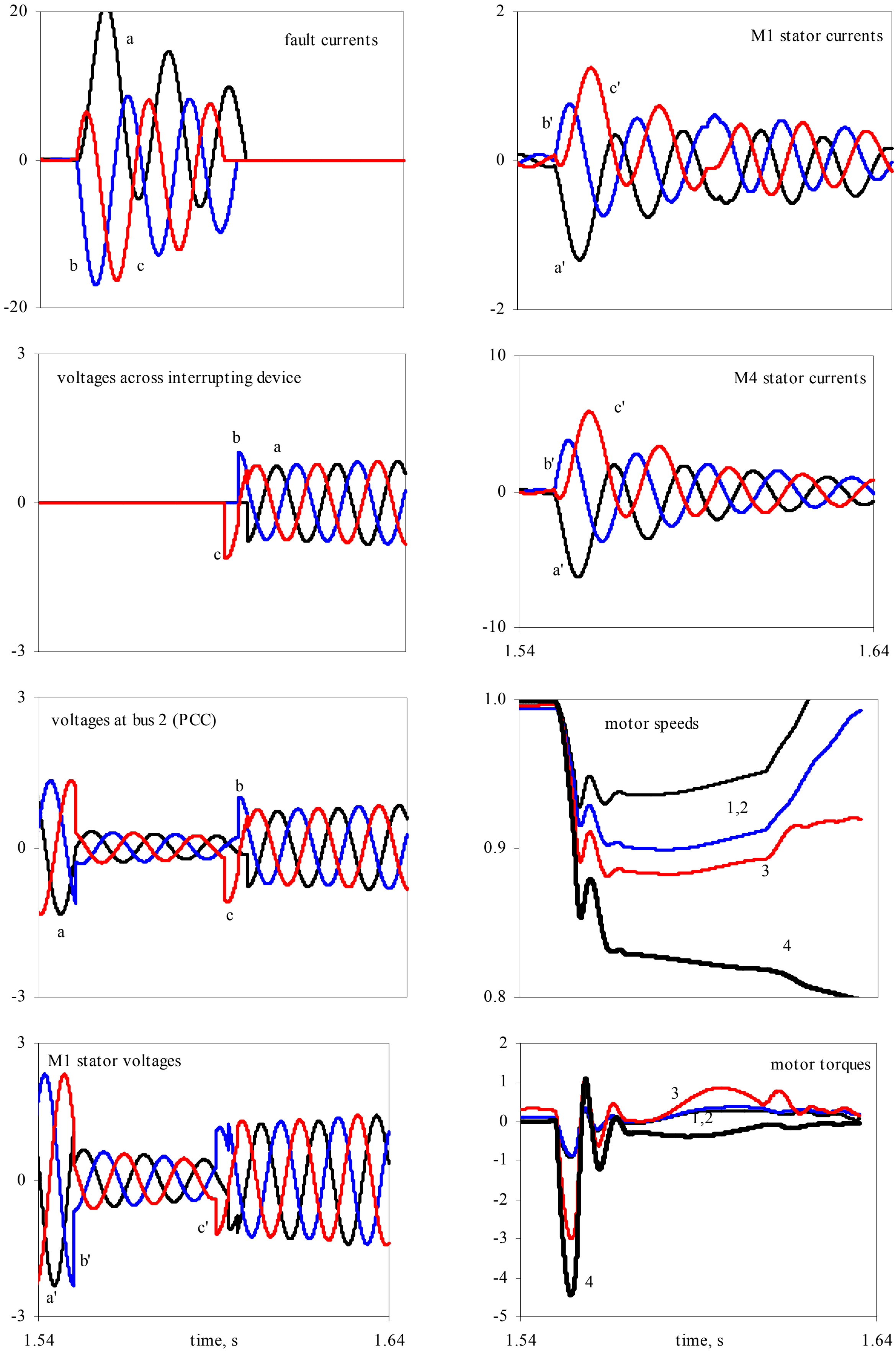

Fig. A.2 Transients with non-C-L protection (all y-axis values are per-unit)