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CURRENT-LIMITING FUSES IMPROVE POWER QUALITY

by

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INTRODUCTION

Voltage sags (sometimes called voltage dips) in power networks due to power system short-circuit faults can cause serious problems for computer systems, adjustable-speed drives, and other industrial and domestic systems [1,2]. The cost of downtime and incorrect operation of equipment is becoming increasingly important. A recent study showed that major industrial users in South Africa suffer annual losses of more than $200 million due to voltage sags [3].

The effect of a voltage sag is dependent upon its magnitude and duration. A curve published by the Information Technology Industry Council (ITIC, formerly known as CBEMA), is often used as a yardstick for the assessment of voltage sags. This curve, shown in Fig.1, defines overvoltage and undervoltage limits as a function of time. The region in between these two limits is a region of acceptable power quality. Although the ITIC (CBEMA) curve is strictly applicable only to 120V single-phase equipment subject to very specific types of voltage waves, it is nevertheless a useful general guide for other power systems.

For a bolted fault to ground the faulted bus voltage will drop to zero. Fig.1 shows that for this case the duration of the fault must be less than 20ms to fall within the ITIC (CBEMA) limits. It follows that the operating speed of protection systems plays a key role in mitigating the effects of voltage sags and the improving of power quality [2,3,4]. The high-speed clearance provided by current-limiting fuses, which have no moving parts, can make a significant contribution to the improvement of power quality.

OPERATION OF CURRENT-LIMITING FUSES

Current-limiting fuses have been used for many years to provide high-speed protection of low-voltage and medium-voltage power systems. Fig.2 illustrates the construction of a typical modern current-limiting fuse. The fuse elements are typically made from silver or copper strip, and have reduced cross-sectional areas in a number of places. They are surrounded by compacted quartz sand in an insulating tube. When a short-circuit fault occurs, the reduced cross-sectional areas heat up and melt very quickly and form a number of electric arcs, which are then controlled and eventually quenched and extinguished by the surrounding sand. The appearance of the arcs corresponds electrically to the sudden switching of the fuse from a low-resistance state to a high-resistance state. This causes a rapid reduction in circuit current, limiting the peak current which is permitted to flow in the circuit, and consequently limiting the “let-through I^2t”. This is the integral of the square of the current over the fault period, and is a measure of the energy which must be absorbed by the circuit components. Fig.3 is a typical test oscillogram showing the breaking of a short-circuit fault current in an a.c. circuit. During the pre-arcing period the current closely follows the available current wave, the voltage drop across the fuse being low. However when arcing begins the fuse resistance and voltage increase rapidly, and the current is forced down to zero well before the natural zero of the prospective current wave.

The peak system current is limited to a level well below the peak available current, dramatically reducing the heating and electromagnetic forces experienced by the power system components.

REDUCTION OF VOLTAGE SAG DURATION

The reduction of heating and electromagnetic stresses (both of which depend upon the square of the current) in power systems protected by current-limiting fuses is well known.

However, it is not generally realized that current-limiting fuses make an important contribution to the improvement of power quality, because they also reduce the duration of voltage sags caused by short-circuit faults.

As an example, consider the simple system shown in Fig.4. This represents a typical motor control center with 2 smaller motors (M1 and M2) and 2 larger motors (M3 and M4), protected by current-limiting fuses rated at 150% of the motor full-load current. For a fault at bus 6, (on the terminals of M4), bus 2 is the "point of common coupling", as far as the other parallel-connected motor loads are concerned [1].

Fig.5 shows the effects on the voltage at bus 2 of a 3-phase short-circuit fault at bus 6, with M1 and M3 initially lightly loaded and M2 and M4 fully loaded. The fault is cleared by operation of the 3 fuses in line 5. These results were computed using the method described in [5], which uses a standard fuse model 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 common 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 (CBEMA) limit 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.

It is necessary that the voltages produced by fuse operation are not so high as to be in the upper region of unacceptable power quality. The waveshape of the voltage transients produced during fuse operation is non-standard as far as the ITIC (CBEMA) 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 (CBEMA) curve, but do not suggest any significant problem [1].

The raising of the bus voltage during the fuse arcing phase aids the re-acceleration of the parallel-connected motors. During the fault the speed of the unfaulted motors does not drop significantly.

If the fault had been at the terminals of one of the smaller motors, M1 or M2, clearance of the fault by the corresponding (smaller) fuses would be faster still, with even less disturbance to the system. The system data used here is typical of such systems. However, for very weak systems, with a very large supply impedance, the short-circuit current may be too low to cause fuse operation in less than one half-cycle [1].

NON-CURRENT-LIMITING PROTECTIVE DEVICES

Devices such as circuit-breakers or expulsion fuses have a different operating principle. The switching arc is extinguished at a current zero of the a.c. wave. This may take several a.c. cycles and during this period no significant current limitation occurs.

Fig.6 shows the computed interruption transients for the example system 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 fuse.

In this case the voltage at bus 2 sags 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 (CBEMA) 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 the 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. This effect has also been noted in measurements on a utility network [4].

Fig.7 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.

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.

Using fuses to improve the power quality of a power system is also a very inexpensive option. For systems where the cost of installing uninterruptible power supplies 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.

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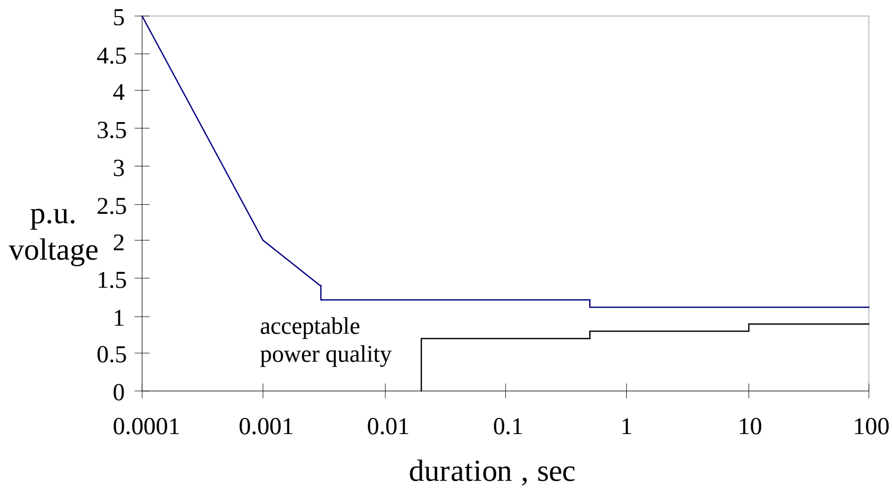

Fig.1 ITIC (CBEMA) curve.

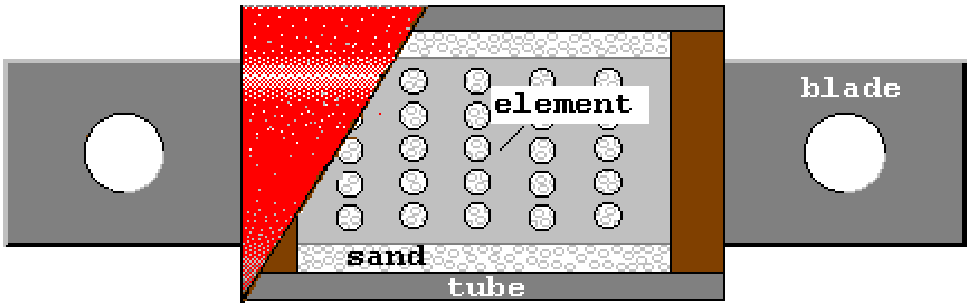

Fig.2 Construction of a typical current-limiting fuse.

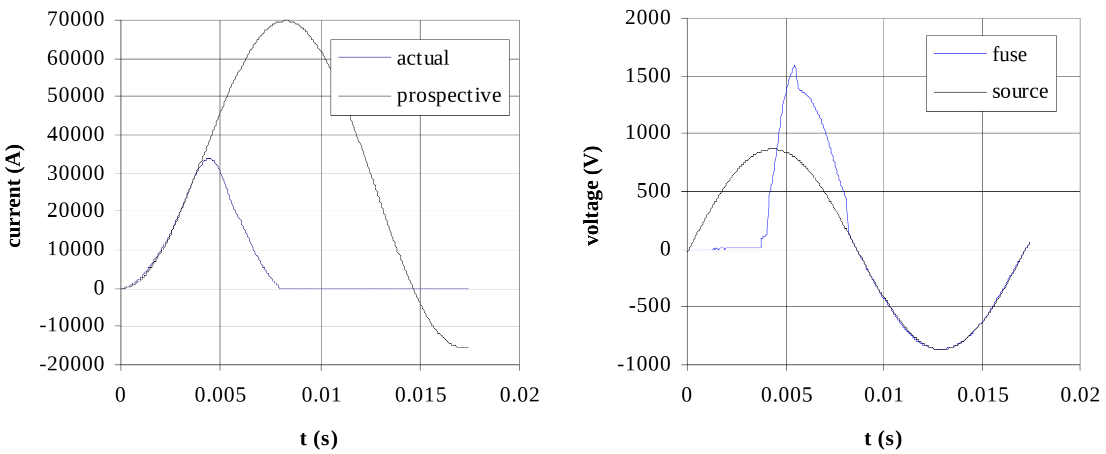

Fig.3 Waveforms for breaking of an a.c. short-circuit by a current-limiting fuse.

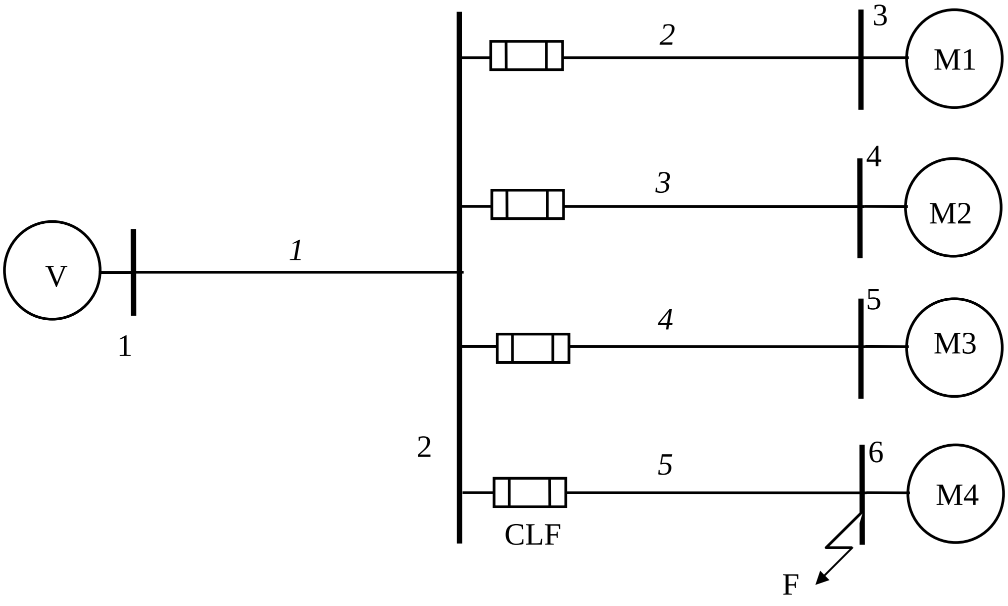

Fig. 4. Example system.

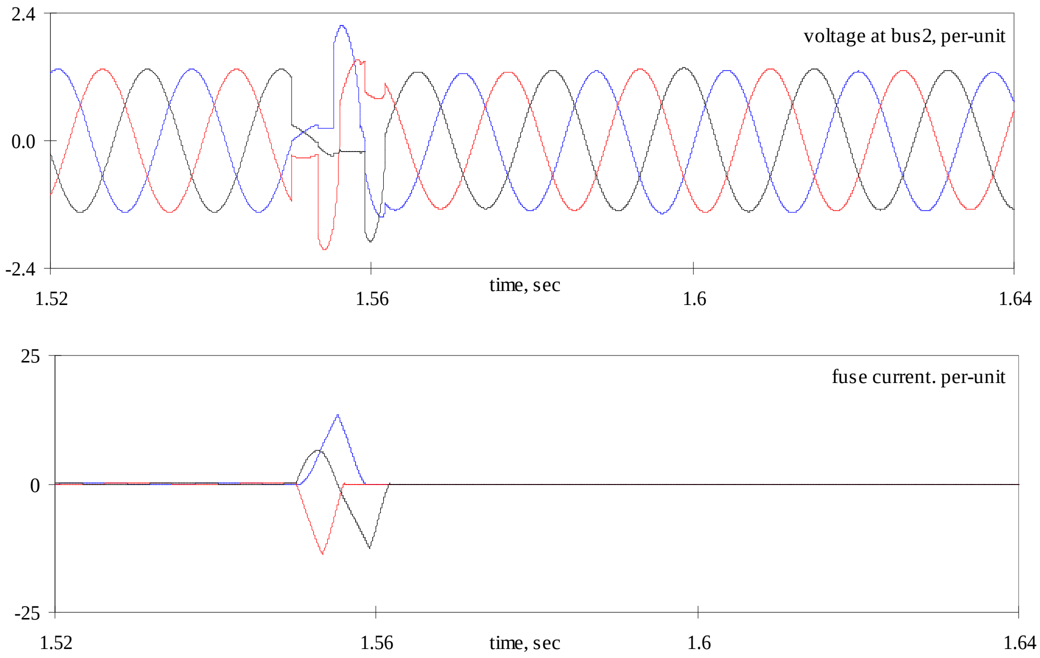

Fig.5 Transients in system protected by current-limiting fuses.

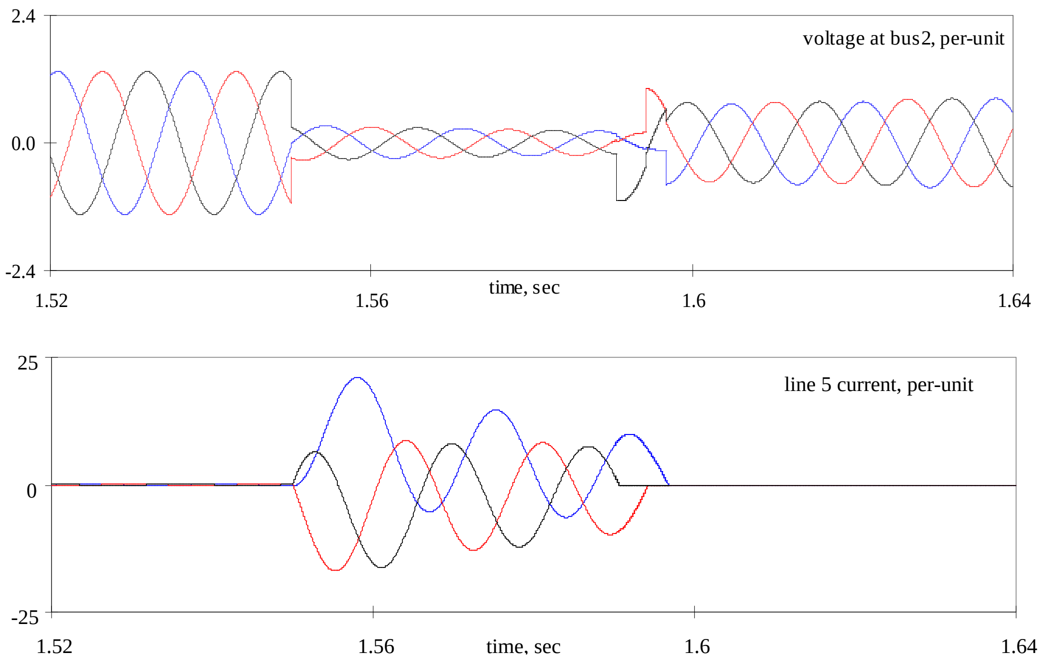

Fig.6 Transients in system protected by non-current-limiting devices.

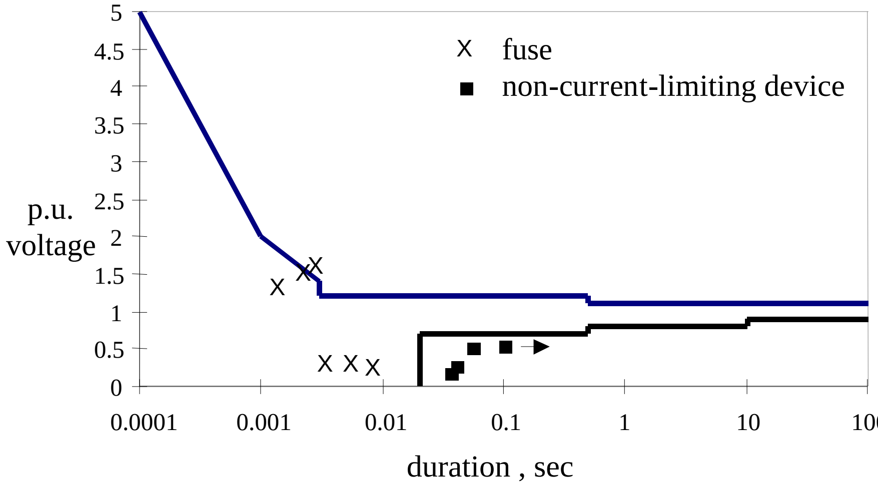

Fig.7 Voltage sags and peaks in relation to ITIC curve.