Protection of large capacitor banks

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(Received 22 October 1982; accepted for publication 30 March 1983)

Large capacitor banks, as used in many pulsed plasma experiments, are subject to catastrophic failure in the event of a short in the output or in an individual capacitor. Methods are described for minimizing the damage and down time caused by such a failure.

PACS numbers: 84.70. + p, 84.60.Td

When large capacitor banks are used for energy storage, there is a danger of the energy being dissipated explosively by a failure of a capacitor or other component.[1,2] In particular, when capacitors are connected in parallel by a bus of low impedance, a short in one of the capacitors or at its terminals will dissipate not only that capacitor's energy, but most of the energy in all the other capacitors. The resulting currents can damage the buses and the other capacitors. The problem is especially serious with electrolytic capacitors operated near their rated voltage, because of thermal runaway and possible voltage reversal. In nonelectrolytic units, the weak link is the bushing lead through which is destroyed by magnetic pressure.

Since the fault currents are typically orders of magnitude larger than the normal discharge current, a logical (but naive) solution is to use a fuse in series with each capacitor. Unfortunately, fuses offer little in the way of protection because the fuse does not clear until most of the capacitor's energy has been dissipated. The current peaks within the first few microseconds of the fault, and the fuse typically requires 30 μs to clear. Furthermore, a failure anywhere in the bank will cause all fuses to blow, and most of the energy in the bank will be dissipated in the resulting explosion. A marginal or defective fuse can also precipitate a fault. If a fuse fails during a normal discharge, the resulting arc can transfer to ground and cause all the capacitors to discharge into the fault, blowing their own fuses in the process. This common method of protection has little to commend it, although it is probably better than connecting all the capacitors directly to a low-impedance bus, provided the fuses are not designed too marginally and care is taken to prevent any arc that forms from transferring to ground. One also has to prepare for a sizable explosion and the prospect of replacing all the fuses in the event of a fault.

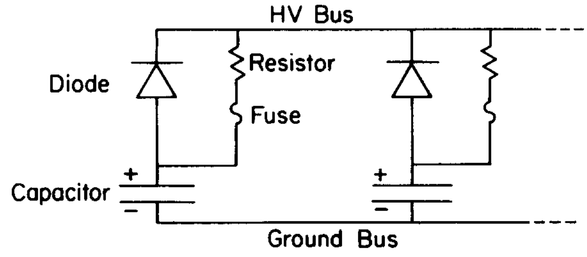

FIG. 1. An elaborate solution for protecting capacitor banks against failure.

These difficulties can be overcome if each capacitor is isolated from the others by means of a diode, so that a short within a capacitor will dissipate its energy only. For electrolytic capacitors, the fault usually is preceded by a steadily rising leakage current. One can sense this current and remove the capacitor from the circuit by a slow-acting fuse before it destroys itself. Such a circuit is shown in Fig. 1. The process is so tame that it is useful to place a resistor and neon bulb across each fuse to aid in locating the defective capacitors. As long as the diodes are good, the capacitors are automatically protected against voltage reversal. However, a fault on the bus side of the diodes will dissipate the full bank energy and will likely destroy all the diodes. Furthermore, if a diode fails by shorting, it leaves its capacitor unprotected, and there is no obvious sign of the failure. Finally, the number of components is large, and it is expensive and time consuming to assemble a bank with this degree of complexity, especially since such assembly may have to be repeated in case of failure.

For most purposes, an adequate compromise is to place a small resistance in series with each capacitor as shown in Fig. 2. The resistor is chosen to drop a small percentage of the capacitor voltage ($\sim 1\%$) at peak current during a normal discharge while limiting the maximum fault current to a tolerable value (say 100 $\times$ the normal peak current). The resistor is designed to dissipate in heat all of its capacitor's energy during a fault without melting itself. In this way, the capacitors and buses are protected against damage, and most of the bank's energy is dissipated in heat rather than in an explosion. Suitable resistors are easily fabricated from short lengths of stainless-steel wire (available as "music wire") with a total mass adequate to dissipate the energy of one capacitor while rising in temperature to about half its melting point, and a cross section-to-length ratio calculated to provide the desired resistance. Such a resistance is normally

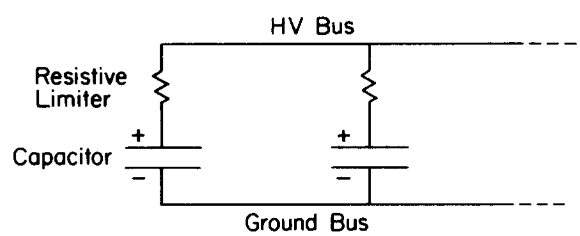

FIG. 2. A simple solution for protecting capacitor banks against failure.

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adequate to overdamp the circuit in the presence of a fault and thus prevent voltage reversal on the capacitor. Failure by shorting of a particular capacitor will, however, result in a significant fraction of the energy in the bank being dumped into the resistor connected to it. One must, therefore, anticipate explosions and protect nearby components. However, the resistors should fail only one at a time, and the resulting explosion should be much less serious than in the case of normal fuses on each capacitor. After such a failure, one only has to be sure that the resistor has cleared cleanly and that no additional damage has resulted from the explosion. Then operation may continue with one fewer capacitor in the bank.

Thanks should go to Bob Vallem, John and Allen Hillery, Adam Gordon, and John Laufenberg. This work was supported by the U. S. Department of Energy.

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Compact device for x-ray section topography with synchrotron sources

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(Received 10 January 1983; accepted for publication 10 March 1983)

An attachment which may be fitted to a standard crystallographic goniometer head for the purpose of taking x-ray section topographs is described and its application in synchrotron x-ray topography is illustrated. A collar attached below the arcs and translation slides of the goniometer head provides a bearing for a rotatable sleeve, concentric with the goniometer axis. The sleeve carries a removable x-ray entrance slit and a removable mirror used for angular setting by optical means. The device is easily transferable between topograph cameras at conventional x-ray sources and synchrotron radiation sources. It can be rapidly aligned at either source.

PACS numbers: 07.85. + n

X-ray topography with synchrotron sources is nowadays widely practiced, high intensity and good beam collimation being among the desirable features of such sources. (The advantages and characteristics of synchrotron x-ray topography are discussed in reviews.[1–3]) Up to now, white radiation synchrotron x-ray topographs have been recorded with a broad incident beam which covers most or all of the area of crystal. In this way data on the overall configuration of defects in the crystal are rapidly collected. However, sometimes one wishes to isolate the image of a particular defect to study its diffraction contrast in detail. This technique, called section topography,[4,5] is most fundamental from the diffraction-theoretical aspect. In this technique the beam reaches the crystal as a narrow ribbon, 10 to 20 μm wide, at a predetermined location. Such restrictions pose difficulties when operating with the large-scale cameras in synchrotron radiation laboratories, and when it is desired to compare section topographs of the same defect taken with both a conventional and a synchrotron radiation source (SRS). These experimental problems have been overcome in the design described here, which combines a standard x-ray crystallographic goniometer head with a mounting for the final x-ray slit. It employs optical alignment methods in a self-contained device which fulfills the requirement of easy transferability from a conventional x-ray topographic camera (remote from the synchrotron radiation source) to the white radiation camera[6] at the synchrotron radiation work station.

The principles of the design can be understood from the overall view of the assembly, including goniometer head and mounted specimen, shown in Fig. 1. There are two major components, the fixed collar A and rotatable sleeve B, both made of brass. The former is attached to the goniometer head below its lower translation slide (or lower arcs in the case of a eucentric head), but does not interfere with operation of the locking ring that couples the goniometer head to the camera spindle. The collar A is basically cup shaped, its internal diameter being large enough to enclose the arcs and slides, and allow them some degree of movement by keys passed through holes in A. The cylindrical surfaces of A and B are coaxial with the vertical axis of the goniometer head,

