SWITCHING OVERVIEW--FUNDAMENTAL ISSUES

H. H. Woodson

Presented at the
2nd IEEE Symposium on
Electromagnetic Launch Technology
Boston, Massachusetts
October 11-14, 1983

Publication No. PR-21
Center for Electromechanics
The University of Texas at Austin
Balcones Research Center
EME 1.100, Building 133
Austin, TX 78758-4497
(512)471-4496

SWITCHING OVERVIEW -- FUNDAMENTAL ISSUES

H. H. Woodson
Center for Electromechanics
The University of Texas at Austin
Austin, TX 78712

Introduction

Good afternoon. It is a pleasure to be here and an honor to be asked to overview and chair this switching session. I feel unprepared for the task, because I have much less experience than those on the program in designing, building, and operating switching systems, and I am sure the same is true with respect to almost everyone in the audience as well. Nevertheless, I have an active interest in switching, and I am involved technically with a group working on switching problems. These have led me to think about fundamental problems of switching.

I will share with you briefly my thoughts on a few of what I consider to be the most fundamental and difficult issues in switching. I hope that these thoughts will be useful to you as you continue your efforts to improve your switching systems.

As we all know, switching is the process by which a branch in an electric circuit changes from being a very good conductor (ideally a short circuit) to being a very poor conductor (ideally an open circuit), or vice versa. There are applications that require both closing and opening switches, and each has its own set of fundamental issues. The interest here is almost entirely in opening switches, so I will confine my remarks to those.

The switching system envisioned here for a discussion of fundamental issues is one which carries current for a relatively long time, typical of charging a storage inductor from a homopolar generator, and then transfers the current to a load in such a short time that circuit inductance dominates the current transfer. After current transfer, the switch must withstand the voltage of the load.

Basic Processes

While carrying current for a relatively long time, the switching system must have acceptably low losses and experience no damage. For a switch with solid contacts, the system holding the contacts together must be strong enough to withstand electromagnetic forces, and the contact resistance must be low enough to avoid thermal runaway and welding or melting of contacts.

For a gaseous switch, the current density must be low enough to avoid pinch and other MHD instabilities that would damage the switch. Solid-state switching elements have conduction properties similar to plasmas and a negative temperature coefficient of resistivity which together make them especially susceptible to current channeling, thermal runaway, and damage or destruction if the current density gets too high. Both gaseous and solid-state switches generally have such high losses that they are usually shunted by mechanical switches until just before current transfer to the load. Furthermore, their allowable current densities are so low that large areas in parallel units are often required to switch substantial currents.

Current interruption or, in the case that most interests us here, the transfer of current from the switching system to a load requires the rapid change of some medium from being a very good conductor capable of carrying a high current to being a very poor conductor able to sustain a considerable voltage without breakdown. There is a fundamental requirement, to be addressed more fully later, for the switching system to accept a well-defined power level and absorb a certain amount of energy during the switching process.

For switching accomplished by separating solid contacts, an arc is drawn between the parted contacts, and the voltage of this arc drives the current transfer, while the arc absorbs the necessary power and energy. The voltage of a simple arc may be too low to transfer the current rapidly enough, in which case measures can be taken to raise the arc voltage. Examples are the application of a magnetic field to the arc, forcing cold gas through the arc, immersing the arc in oil, forcing the arc into extended contact with solid material to cool the arc, or placing multiple gaps in series. If these measures do not provide sufficiently rapid current transfer, more heroic measures to produce arc voltage may be necessary, such as fuses and explosive switches.

In all cases of current interruption, including gaseous and solid-state switches, the fundamental problem is the rapid transition from numerous and mobile charge carriers to high dielectric strength. This means removal or recombination of charge carriers, and whatever can speed those processes will speed the switching process.

The voltage the switch can withstand after current interruption or transfer increases at a rate determined by the rate of depletion of charge carriers. This rate of rise of recovery voltage (RRRV), usually measured in kV/μs, can vary by four orders of magnitude or more, depending on the gas and conditions in the arc. Similarly, it can vary dramatically for solid-state switches.

Time is critical in switching. How long the switching system must carry current before the switching operation occurs is important. How fast the current is to be transferred from the switch to the load is a crucial question, along with how fast and how high the load voltage will rise.

Yet another time consideration is whether the switch is to be single-shot or rep-rated.

Because the switching system must produce a voltage opposing the switch current in order to transfer the current to the load, the switching system must absorb power and energy to accomplish the switching. There is no fundamental specification as to what form this absorbed energy must take. Most often, it is absorbed as thermal energy, in heat of fusion, or in heat of vaporization. It can be stored electrically in a capacitance, magnetically in an inductance, inertially in a flywheel, or potentially in a spring, at least in theory. I am not sure that such opportunities have been explored adequately, but they may have been.

Capabilities from Experience

I know that a lot of clever and inventive people have worked on a number of novel switching systems for special applications. Many of those people are here today presenting papers on their work, and their efforts are to be applauded.

I think that more attention should be paid to the work of another set of very able people who have spent many years to develop economical, dependable circuit breakers at the highest current and voltage ratings possible for electric utility applications. Many years of effort have led to dependable interrupters that can handle steady-state currents of up to about 10 kA, interrupt fault currents on the order of 100 kA, and withstand voltages of several hundred kV with RRRV of around 10 kV/μs. There has been little difficulty in operating interrupters in series to achieve higher voltage ratings, but paralleling interrupters for higher current rating has been difficult and costly. It has been more practical to segment circuits so that each segment can be handled by a single interrupter.

Much thought and effort have gone into circuit breakers for power systems, and, in my opinion, careful attention to this experience should benefit the EML switching community.

Switching Requirements for Railguns

Railguns appear to need currents in the range of 1 MA and voltages of from several kV to several tens of kV. The switching needs to be done in μs to ms. Because of the relatively low voltage requirement, the switching can probably be far from perfect, provided decreased efficiency is acceptable. These requirements are more severe than utility system requirements in terms of current level and switching time, but are much less severe in terms of voltage.

Summary and Conclusions

First, let me laud the EML switching community for its ingenuity in developing novel switch concepts for the unique duty required. Second, let me observe, maybe unjustifiably, that there may be ways to apply electric power system circuit breakers to these switching requirements if the fundamental limitations of interrupters are recognized, and the entire energy delivery system is redesigned to accommodate these limitations.

Third, it is my impression that too little attention has been paid to switching with electromechanical systems and with solid-state systems. I think there may be opportunities in these areas that have not been explored but may have potential for success.

Finally, let me observe that these suggestions for alternatives to current directions may be futile. You may have already examined them and found them to be wanting. On the other hand, if you haven't looked, maybe you should.

Thank you.