High-Voltage Equipment

The safe and efficient handling of high-voltage electric current is becoming an increasingly important issue in the development of advanced energy and defense technologies. As scientists and engineers begin to press the limits of today's high-voltage equipment, there is a crucial and growing need to better understand the fundamental interactions of strong electric fields, currents, and voltages with the materials and substances used to control them.

In the electric power industry, for example, there are compelling economic motivations to reduce the amount of energy lost in the transmission and distribution of electricity from the power plant to consumer. The amount of electricity lost is estimated to be on the order of 10 percent of total sales, valued in terms of today's prices at about $15 billion per year.

The principal strategy for solving this problem is to reduce the electrical current and its associated losses by increasing the voltage. A doubling of the voltage halves the current, which in turn reduces the losses due to electrical resistance by a factor of four. Hence, with the advent of appropriate enabling technology, high-voltage power lines now operating at 765 kilovolts (kV) might be able to operate safely and economically in the higher ranges of 1100 to 1500 kV, cutting losses by 50 to 75 percent, respectively.

In 1974 Seed Money researchers laid the scientific foundation for the development of several key advancements in such technology. Their work focused in particular on improvements in insulating materials, known technically as dielectrics, which would be required to handle the higher voltages.

High-voltage devices such as switches, connections, and transmission lines are protected from electrical short-circuiting by wide gaps between the so-called "hot" side of the circuit and the ground. Under ideal conditions, this gap would be filled with a perfect insulator, keeping the two sides safely separated, while simultaneously minimizing space and cost.

More typically, however, a safe device is large, cumbersome, and costly. The gap is usually filled with certain liquid dielectrics, such as oil, or as is often the case in high-voltage devices, the gap is made wider and filled with ordinary air or other gases known to have special insulating properties.

Unfortunately, under the stress of strong electric fields, which become stronger with higher voltages, the insulating properties of gas dielectrics break down. For a brief moment, the gas becomes a conductor of electricity, rather than an insulator, allowing the high-voltage current to jump across the gap with disastrous results.

Seed Money researchers were aware that certain gases were more resistant to "breakdown" than others and set out to investigate the underlying causes. The research examined the effects of strong electric fields on the behavior of gases at the atomic and molecular levels.

In particular, the work focused on the delicate balance between the rates of production and absorption (elimination) of a special class of electrically charged particles, called "free electrons." These particles exist naturally in minute amounts in every gas and, if concentrated in sufficient number, can carry a large electric current.

The researchers hypothesized that breakdown occurred when this balance tipped too far in favor of production. This would result in a nearly instantaneous population explosion of free electrons, which would be followed immediately by a large, violent electrical discharge.

Accordingly, they searched for a means by which certain electron manipulating properties could be introduced into gas dielectrics so that the balance would be tipped the other way. They looked for two properties in particular, one that promotes absorption, which eliminates free electrons best when they move relatively slowly, and another complementary property that promotes scattering, which works best on the faster free electrons and slows them down.

In this line of research, they were highly successful. Gases were identified that possessed the desired properties, and optimal mixtures were formulated that both improved insulation performance and lowered costs.

Further, in the course of the investigation, the Seed Money researchers discovered that toxic chemicals could be produced by sparks in the most commonly used gas dielectric, sulfur hexaflouride. This finding alone revamped industry work and safety procedures and greatly reduced previously unknown, but nevertheless prevalent, occupational risks.

Importantly for the future, this research contributed significantly to our understanding of how gases, when subjected to high electric fields, either resist or conduct high-voltage current. Understanding this behavior is of great importance to other advanced technologies, such as those which require extremely fast and durable high-voltage switching devices. These include high power lasers and particle beam accelerators, both of which are currently the subject of active research interest. They also include certain schemes for obtaining a virtually inexhaustible supply of power from a nuclear process that mimics the sun, called fusion energy.

Altogether, this Seed Money accomplishment generated considerable interest in the high-voltage equipment industry. It was the subject of several well attended international conferences and the focus of much follow-on work funded by private sector manufacturers and research institutes.

Perhaps more significantly, basic research into the fundamental