SCR Is **50** Years Old

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If you can look into the seeds of time,
And say which will grow and which will not,
Speak then to me.
—Macbeth, Act I, Scene 3.

The first silicon-controlled rectifier (SCR) was produced in late July 1957. This was the first practical commercial device of what eventually became known as the thyristor family, and it began a revolution in power electronics and control. This year we celebrate the 50th anniversary of the SCR, and it is appropriate that we note some highlights from its history. This article focuses more on the application of SCRs and less on the history of rectifier devices or solid-state theory and appropriately so for the IEEE Industry Applications Society (IAS) members. A companion article focusing on the process of innovation was presented at the 2007 IEEE Conference on the History of Electric Power [1].

Ten years earlier, in 1947, Bell Telephone Laboratories (BTL) developed the point-contact transistor. The transistor was the first solid-state device to use modern semiconducting materials such as single crystal germanium and silicon. The announcement of this development spurred research into electrical conduction in solids. Together, these two milestones in solid-state devices provided a cornerstone for what later became the modern era of power electronics. One need only consider the number of power electronic devices that we encounter each day in our factories, homes, and offices to understand the significance of these achievements.

The *IEEE Dictionary* defines SCR as "an alternative name for the reverse blocking triode thyristor." It is a four-layer, three-terminal, solid-state device that controls current flow. It is made from single-crystal, high-purity silicon (semiconductor) material. A p-type layer acts as an anode and an n-type layer acts as a cathode; the p-type layer closer to the cathode functions as a gate. It is a solid-state functional equivalent for the older gas-discharge or mercury-arc controlled rectifier known as thyratron.

THE SILICON CONTROLLED RECTIFIER WAS A DREAM FOR BILL GUTZWILLER.

Switching Mode Operation

Much of the importance of the SCR can be traced to the window it opened to the wider understanding of the switch-mode operation. The tremendous benefits of the switching operations in power electronics came into the public domain following the introduction of the thyratron in 1921. In that era, switching operation primarily meant phase control. The theory of phase control was well advanced by the time the SCR became available. Although phase control circuit theory was widely known, the complexity of those circuits and the fragile nature of the rectifier devices greatly restricted practical applications of phase control. The SCR largely overcame both obstacles to using phase control devices, opening doors to a wider application of switch-mode operating devices, including time-ratio-control (TRC).

From the beginning, the SCR normally operated as a switch-mode device, whereas the transistor was viewed as operating in a continuous or semi-steady-state mode. It took time to unravel the previously unknown characteristics such as stray capacitance and other dynamic properties of the transistor and later the SCR. When viewed as a continuous mode device, the amount of power dissipated in the device can equal or exceed the amount of power controlled, for example, when operating at maximum power transfer wherein the circuit voltage is shared equally across the transistor and the load it is controlling. It is this switching aspect of the SCR that allowed it to control very large amounts of power when compared with that dissipated in the device. Several years later, it was realized that transistors could also operate in a switching mode and generate some of the operating benefits previously available only from the SCR. With this realization, some of the distinctions between the SCR and the power transistor became less tangible.

In the normal "off" state, the device restricts the current flow to the leakage current of the device, and power dissipation is relatively low.

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When the gate to the cathode voltage exceeds a certain threshold, the device turns "on" and conducts current in the forward direction (again power dissipation is relatively low due to low forward voltage drop in the device). It is only during the very brief interval of time when the device is switching that circuit conditions approach maximum power transfer, and power loss in the SCR approaches the amount of power passing through the device, although the cycle-average power remains small. In theory, the faster the switching, the higher the power efficiency of the control device. Recently available devices operate at switching speeds ten or 100 times higher than originally possible with the SCR. In practice, it is not so simple, but that is another story. In the early days, the switching characteristics of the SCR had to be worked out before it became the useful device it is today.

The Inventors

In 1956, General Electric Company (GE) had 16 electronics businesses and five e-labs; sales volume from electronics alone was greater than it had been for the entire company only 15 years earlier. The commercial environment in the world of electronics was extremely competitive and chaotic. New products were introduced almost everyday; who was to say which product would succeed, which would pass from the scene, and where do you invest your time and money? Even though GE announced products, some of its own departments were unable to get samples of the new products, whereas in other cases, those outside the company seemed to get those important samples. The patent situation became very complicated, and sometimes the technology was licensed without obtaining patent protection.

Gordon Hall led a very small team of power engineers in Clyde, New York, that produced the first SCR. At that time, GE management underestimated the significance of the new development, but so did most of their competitors. Many technologists of that era assumed that the new device would be used to either control loads with a few kilowatts of power or trigger the thyratrons or ignitrons, which were then the muscle of the power electronics world. But few had any idea that it would replace the established mercury-arc controlled rectifier devices.

GORDON HALL DID THE ACTUAL DEVELOPMENT WORK THAT PRODUCED THE FIRST SCR DEVICES.

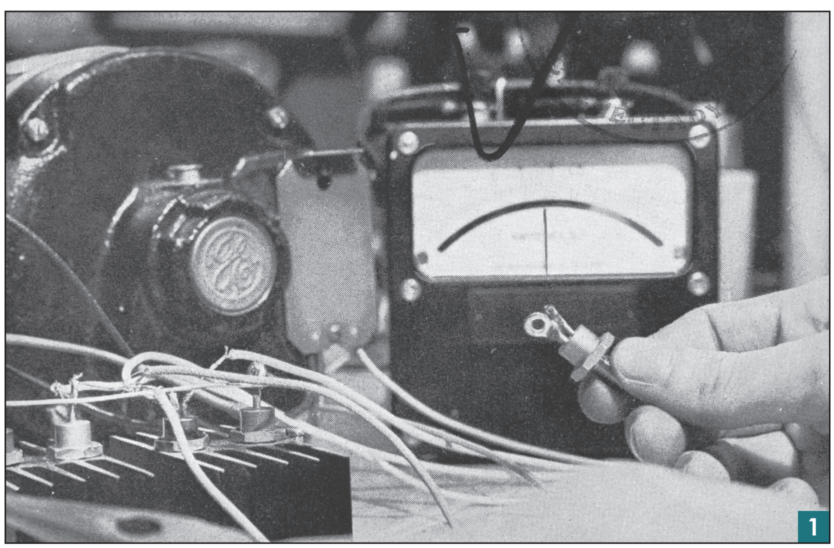
Once the device was developed in the laboratory, conversion into commercial products proceeded along two lines. One involved rapid assimilation into applications involving only small amounts of power and where only small amounts of capital were at risk. Applications involving larger-power blocks were much slower, and growth was more tentative. For the larger applications, progress required courage and resources. It required the considerable resources of large companies whose management and staff not only possessed necessary competence but also high confidence in their abilities to succeed with this new technology. Should they not succeed for any reason, it might have serious financial consequences for their entire corporate organizations.

GE began promoting the device in August 1957. In response to a press release by GE, the 28 December 1957 issue of *Business Week* carried a two-page article titled "New Way to Change AC to DC" [2]. The article described a new electronic device called a "controlled rectifier," and the reader was informed that it was made from silicon, then a new material used to make transistors. Three weeks later, a similar article in GE's internal magazine, *Monogram*, called the new device a "silicon controlled rectifier" [3]. There was no unanimous opinion on what to call the new device, as we shall learn later.

Characteristics, Ratings, and Prices

The prototype SCRs available in 1957 worked at 300 V and up to 7 A (Figure 1). The diameter of the junction was 3 mm, and the price was US$60 each. The amount of control power required to trigger individual devices was about 15 mW. Switching speed was limited to a maximum dv/dt of about 15 μs, and the maximum rate of change in current was unlisted. Today, SCRs are made with voltage ratings as high as 7,500 V and with current ratings up to 3,000 A (RMS) per device.

Early on, many people misjudged the role that the SCR would ultimately play. They considered it as being a tiny device capable of only a small power rating similar to the transistor. Power transistors were being developed at several places, but even a husky one was capable of controlling only 37 W



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Demonstration of prototype SCR in 1957. (Source: Schenectady Museum & Suits-Bueche Planetarium [3], used with permission.)

compared with the 2-kW capacity of SCRs. The key missed by many people was the switching nature of SCRs, rather than the continuous-current mode of the transistor. The fast-switching behavior of SCRs reduced the power loss that was dissipated into the rectifier device.

The new devices were physically small and incapable of absorbing much power dissipation in the event that something did not work as it should have, or if it was subjected to a voltage spike. Voltage surges that the older mercury-arc technology easily absorbed caused catastrophic failure of the new solid-state devices. Francois Martzloff came to GE in the early 1960s and led the way in understanding surges and how to protect against them. At the time, the thyrector (selenium, polycrystalline device) was GE's primary surge protector. Later, metal-oxide varistors (zinc oxide) were available with greatly improved characteristics.

The Work of Others

The team at GE that produced these first units had been informally working on them for some time, with many believing that it would not be easy to achieve a practical unit. Researchers at BTL and the Radio Corporation of America (RCA) were aware of the concepts and were working on devices with somewhat similar characteristics but focused on only tiny devices with small ratings (milliwatts). Some attribute this to an unexplainable blind spot on the part of William Shockley. The work at BTL was directed toward producing a solid-state replacement for the small gas thyratron tubes used in automatic electronic telephone exchanges. BTL engineers chose to call their device "thyristor" as a hybrid term derived from thyratron and transistor. Simultaneously, researchers at RCA perfected a germanium device with the same characteristics and picked the same name for it [2]. This device was very different from the SCR (silicon) device produced at GE. Indeed, the name thyristor was in use, but the device was not the same.

Many people contributed toward the development of the SCR, and there are several claims (sometimes conflicting) as to who did what and when it was done. This account is largely based on a similar one given by Lyle Morton in July 1981 but with the addition of information that became available more recently (Note: Curtis Herskind hosted a picnic on 19 July 1981 at his home to begin collecting oral histories and artifacts from his friends for use in the book. The list of invitees included Marv Morack, Bernie Bedford, Ray Pohl, Mal Horton, Jim Hudson, and several others. Phone calls were prearranged to Gus Schmidt and Dick Hoft.) [4].

BTL had announced the point-contact transistor ten years earlier. In the decade between the development of the transistor and the SCR, researchers at several institutions had distant visions of a solid-state controlled rectifier but were frustrated by multiple obstacles, including the lack of a suitable semiconductor material, and most accepted that it was not really practical. Product announcements by GE caught many of their competitors by surprise, but for some it did not take long to catch up.

The SCR was a dream for F.W. (Bill) Gutzwiller. Bill persevered in his vision of a solid-state device that would replace the thyratron, the gas discharge (mercury-arc) controlled rectifier of the previous generation. Bill coined the term "silicon controlled rectifier," and his primary role was to commercialize the device [5], [7].

Solid-State Theory

The SCR did not burst forth in a fully developed form but required nurturing and cultivation to become the revolutionary device that we know today. The theory of solid-state materials developed during the ten-year period prior to 1957. In 1947, BTL announced the invention of the point-contact transistor using germanium material. In 1952, Robert N. (Bob) Hall at GE described the PIN junction, while shortly thereafter Robert Shockley at BTL described the junction transistor. Nick Holonyak worked at BTL before joining GE. While at BTL, he was part of the team that invented the four-layer device (p-n-p-n) that in due course lead to the SCR [6], [9]. Many credit Nick with the working knowledge of solid-state physics that produced the SCR. However, Bob Hall at GE also understood the theory and played an important role in developing the SCR [10]. During an interview in 1981, Bob described a few research centers where he felt the knowledge to produce such devices existed during the 1950s and early 1960s. The main focus of his interview was the work he had done on the tunnel diode, but he digressed to comment on the circumstances surrounding the SCR, giving credit for its development to Holonyak. His remarks on Holonyak must have been directed toward the theory of solid-state material and not toward the practical device that resulted. Hall named several research centers that he considered had the capabilities and resources to conceive of the SCRs but for some reason did not do so.

Lyle Morton reported that theories necessary to produce an SCR already existed in 1957 [4]. In addition, applications for which it would be used were also in existence. He attributed the delay in developing the SCR to the lack of an appropriate material to achieve a suitably low forward voltage drop. Production of an SCR with sufficiently low forward conduction voltage drop requires silicon material that is extremely purified, more so than required for a transistor. Impurities present in the bulk material represent dislocation sites that disrupt the orderly flow of holes and electrons, increasing on-state conduction losses. F. Hubbard Horn, working with Bob Hall at GE as a semiconductor materials specialist, spotted a sample of silicon with the required purity, brought it home, and, within three months, GE produced its first SCR. Others were capable of and might have made the same discovery.

Gordon Hall (not related to Bob Hall) did the actual development work that produced the first SCR devices. He worked in Clyde, New York, along with Bill Gutzwiller. He was assisted by Nick Holonyak at GE's e-lab in Syracuse and by Bob Hall at GE's Research Lab in Schenectady. In addition, John Harnden at GE's General Engineering Laboratory located in Schenectady took an active role in the development work following the article in the *Business Week*. It may not be possible to sort out the relative contributions of each of these persons, and the reader is referred to the references at the end of this article for additional information. Perhaps the most important point to realize is that the early work was done by a small group of technologists in Clyde, New York, working on a very small budget. Advocacy by Bill Gutzwiller for such a device seemingly focused attention on it, inducing others in his organization to actually produce the same. Then as he explains, it was up to him "to do something with it."

Nomenclature

Once the SCR came onto the world stage, many people in various places played important roles in further developing it into the revolutionary device that it became. However, the name SCR was not the one chosen by GE for the device but rather some at GE chose the name "silicon controlled rectifier" or SCR. In July 1959, Westinghouse announced a solid-state controlled rectifier called "trinistor." By 1966, L.F. Stringer and L.R. Tresino used the name thyristor. Some in Europe adopted the name thyristor more quickly than others elsewhere. This was partly due to IEC TC47 formed in 1960. It was several years before the name thyristor became universally accepted.

Commercialization

Gutzwiller was an early advocate of this new device, beginning even before it was developed. His crusading efforts resulted in the GE *SCR Handbook*, of which he was the editor [7]. The *SCR Handbook* was used as a primary source by a number of companies to design and build their SCR circuits.

Larger Ratings and New Applications

Charles H. Titus at GE was quick to see the potential the new device offered, if larger ratings were available. Rather than waiting for someone else to do it, he decided to press forward with the use of SCRs for larger applications. His personal style was blunt, but he was often right in his opinions. He spurred interest in the fabrication of devices with larger-power ratings and the use of those larger devices to a wide range of applications, and his position within GE management allowed him to push for results. As a result of his efforts, GE established a facility in Collingdale, Pennsylvania, to build larger SCRs and diodes. GE was the first to operate devices in series/parallel arrangements to achieve the high-power requirements of high-voltage dc power transmission.

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References

[1] E. L. Owen, "Fiftieth anniversary of modern power electronics: The silicon controlled rectifier," presented at the 2007 IEEE Conference on the History of Electric Power, NJIT, NJ, 3–5 Aug. 2007.

[2] Anonymous, "New way to change ac to dc," *Bus. Week*, pp. 115–116, Dec. 28, 1957.

[3] Anonymous, "New semiconductor horizons seen as success marks development effort," *Monogram*, cover and p. 6, Jan. 1958.

[4] C. C. Herskind and Marvin M. Morack, Eds., *A History of Mercury-Arc Rectifiers in North America*. Piscataway, NJ: IEEE, 1987.

[5] F. W. Gutzwiller. (2003). *Journey to Windward*. [Online]. Available: http://www.semiconductormuseum.com/Transistors/GE/OralHistories/Gutzwiller/Gutzwiller_Index.htm

[6] N. Holonyak, "The silicon p-n-p-n switch and controlled rectifier (thyristor)," *IEEE Trans. Power Electron.*, vol. 16, no. 1, pp. 8–16, Jan. 2001.

[7] *SCR Manual*, 2nd ed. General Electric Co., Auburn, NY, 1962.

[8] J. D. Harnden, Jr., "The controlled rectifier: Key to the continuing control renaissance," *AIEE Trans.*, vol. 78, pt. 1, pp. 1006–1012, Jan. 1959.

[9] Oral History Interview with Nick Holonyak, IEEE History Center.

[10] Interview with Robert N. Hall, Hall of History Collection, Schenectady Museum and Suits-Bueche Planetarium, Schenectady, New York, 1981.

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