Origins of the Inverter

David Prince probably coined the term *inverter*. It is unlikely that any living person can now establish with certainty that Prince (or anyone else) was the originator of this commonly used engineering term. However, in 1925 Prince did publish an article in the *GE Review* titled "The Inverter" [1]. His article contains nearly all important elements required by modern inverters and is the earliest such publication to use that term in the open literature.

The idea of using grid control in combination with phase retard to modulate AC power originated with others about four years earlier. However, Prince appears to have been the individual who took Alexanderson's expression "inverted rectification" and created a single English-language word *inverter*. It conveys the idea of a rectifier except functioning in an inverted mode of operation, hence inverter.

What's in a name? That which we call an inverter by any other name would be an inverter. Rissik addresses the issue of terminology in the preface of his book, published in 1935 [4]. He provides the following German-English equivalents:

"German [is] *a language singularly rich in pithy terms and descriptive phraseology. ... A current convertor (stromrichter) is thus a device for converting alternating to direct current or vice versa, or for converting alternating current of one frequency into alternating current of another frequency. This general term then includes the more specific terms: rectifier (gleichrichter), inverter (wechselrichter), and cyclo-convertor (umrichter)."*

By 1936, Prince's inverter appeared in literature from all corners of the world, Europe and Japan among them. It was in common use in English technical publications or its equivalent word was used in other languages.

In 1925, Prince defined *inverter* as the inverse of rectifier. In so doing, he depended upon his audience having a clear mental abstraction of rectifier and built upon their pre-existing concepts. The term *rectifier* was in common use for more than two decades prior to 1925. It was understood to mean any stationary apparatus or rotating commutator for transforming alternating into direct current. (Rotary converters, later known as synchronous converters, were in use by 1892 to convert AC power into DC power. Rotary converters were manufactured until the 1950s, when germanium diodes became available. When operated to convert DC power to AC power, rotaries were dubbed "inverted rotaries." The distinction between *rectifier* and *converter* was sometimes vague, perhaps even arbitrary, but often based on use of static or non-rotating versus rotating parts.)

Prince explained that an inverter is used to convert direct current into single or polyphase alternating current. The article explains how "the author [took] the rectifier circuit and inverted it, turning in direct current at one end and drawing out alternating current at the other." Use of the word *inverted* conveys the idea of turning something upside down. What was turned upside down? Clearly, he did not mean to invert the rectifier device(s) or rectifier circuit; their orientation remains the same. Rather, he meant to invert the function or operation of the rectifier. That is why he said to draw in direct current and push out alternating current, to emphasize a new mode of operation.

However, direction of direct current is not reversed. It is direct potential (voltage) at the rectifier terminals that is inverted or reversed. Because potential is reversed with current continuing in the same direction as before, the flow of electric power is also reversed or transferred from the DC system to the AC system.

The inverse of rectification was not an obvious extension of prior art. It required several imaginative steps by Prince to bring his readers to comprehend conversion of electric current of one form (direct) to another form (alternating). Among those innovations was grid control of current conduction. Prince was not the originator of that idea, but built upon it.

Today, the IEEE dictionary similarly defines *inverter (electric power)* as "a machine, device, or system that changes direct-current power to alternating-current power." This modern definition avoids the inconsistency of Prince's historic definition.

The term *rectifier* is often confused with similar or related terms and phrases. It is sometimes used to denote rectifier element (device) or rectifier circuit when rectifier equipment is intended. Rectifier elements can be physical devices or circuit entities. In either case, rectifier elements allow current to flow in only one direction, blocking its flow in the reverse direction (i.e., diodes, thyristors). The property of rectifier elements that permits only unidirectional current flow causes some persons to call them electric "valves," being analogous to check valves in hydraulic circuits. (In some places, they are still called valves.) Rectifier circuits are electrical circuits containing rectifier and other circuit elements (resistors, capacitors, etc.) interconnected into prescribed paths or current conduction, the whole assembly (or network) providing the function of rectification.

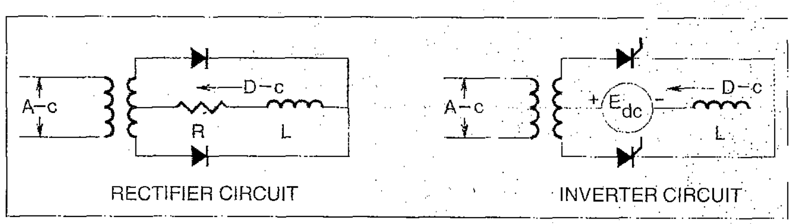

Fig. 1. Prince's rectifier and inverter circuits.

His Idea

Prince reviews prior art by first examining operation of a single-phase full-wave center-tap rectifier circuit. The DC output of the rectifier circuit includes both passive resistance and reactance. His figures provide ideal waveforms of most circuit variables, including potential and current at AC and DC terminals. His Fig. 1 is depicted here, on the left side of the figure, and is identified as "rectifier circuit." This figure is identical in topology to Prince's, except that modern symbols for rectifier circuit elements replace his archaic vacuum tube (diode) symbols. With this small change, his figure is identical to any modern single-phase full-wave center-tap rectifier circuit.

Prince then introduces grid (gate) control of rectifier conduction period and inserts a source of CEMF in place of the load resistor (counter-EMF, as produced by DC machine to distinguish it from voltage in the rectifier system or E.M.F). These innovations are included in his Fig. 3. The inverter circuit shown in Fig. 1 here is, similarly, a modern rendering of his Fig. 3 except that it uses contemporary rectifier symbols. If polarity markings for the CEMF are correct as shown in his figure, power flow is from the AC to DC terminals, and the circuit functions as a rectifier (motor). Obviously, it is necessary to reverse the polarity, and he says as much.

Rectifier Devices

Rectifier devices available to Prince in 1925 were of three basic types: mechanical rectifier, electrolytic "cells," and high-vacuum or gas-discharge "tubes." Mechanical rectifiers consist of rotating commutators driven by synchronous motors and were in use prior to 1893. Electrolytic cells also originated prior to the turn of the century and were the second rectifier devices available. They evolved experimentally from electrochemical research before existence of the electron was discovered by J.J. Thomson in 1899. Similarly, the Edison effect (1883) was discovered before knowledge of the electron, but no immediate application was made of his discovery. It was the Cooper Hewitt patents on mercury-arc rectifiers (1901) and DeForest's three-element valve (audion, 1907) that opened the way for gas-discharge tubes. Later, work by Langmuir on pure electron discharge led to hot-cathode high-vacuum tubes, called "Pliotrons" (1914). (In 1925, Prince described his inverter using Pliotron or high-vacuum tubes.)

Following WW1, Langmuir turned his attention to arc discharge tubes, leading to the "Thyratron" [6]. Although available to Prince and his associates at GE's Research Laboratory in 1925, Thyratron was a proprietary development at General Electric and not openly discussed outside the GE fraternity for another three years. (Thyratrons are a mercury-arc equivalent of modern solid-state thyristors.) At the same time that Prince's article on the inverter was published, Alexanderson demonstrated application of Thyratrons to an assembled multitude of GE management and engineers at Camp Engineering [5]. In his presentation, Alexanderson foresaw numerous applications of grid (gate) control and phase retard but mostly those circuits using "natural (external) commutation." In his 1925 article, Prince also illustrated his inverter in terms of natural commutation.

Three years later (1928), Prince published another article disclosing outside the GE community the idea of "forced (internal) commutation" [3]. The name Thyratron was coined in 1921, probably by L.A. Hawkins of GE. Some people attribute the name Thyratron to Alexanderson, either because of his renown or because they know his surviving wife's first name is Thyra. It is lore that makes a good story, but it is not true. Thyra was his second wife, whom he married in 1949, long after the name for the tube was coined. The name Thyratron is a combination of two words in Greek, *thyra* being equivalent to door (the idea of opening a door or gate) and *tron* signifying instrument or appliance. The name *thyristor* is also derived from the same Greek root for door (Θυρα), except combined with a suffix *istor* associated with modern solid-state devices, as in *transistor* (the transistor having been announced in 1948).

Rectifier Circuits

Several well- and lesser-known rectifier circuits existed, including half- and full-wave, single- and polyphase, single- and double-way, and star and bridge circuits. The "Graetz" circuit (Leo Graetz, 1897) was developed nearly 30 years prior to Prince's inverter. The Graetz circuit was associated with Nodon (electrolytic) rectifier elements but was of far more significance in that it disclosed the principle of the double-way circuit. Double-way circuits are those distinguished by current conduction occurring through two rectifier elements in series in opposing arms of the circuit. (e.g., the familiar bridge circuit). It was not used for power rectifiers in 1925 as it requires independent cathodes to function in its normal mode of operation.

The "Churcher method" was more an equipment than a circuit. It was also associated with electrolytic rectifiers, the rectifier circuit of which was single-way single-phase full-wave center-tap (as used by Prince). The Churcher method did not survive in name to identify a particular class of circuits, as did Graetz's name.

Subsequent Developments

In 1929, many changes occurred (including the beginning of the Great Depression). Prince began turning his attention away from rectifiers and toward power circuit breakers. Meanwhile, Alexanderson turned his full attention to power electronics. (Alexanderson was forced to choose between working for GE and RCA. Radio Corporation of America was established in 1918 to exploit his [Alexanderson's] alternator for radio broadcast work. During the intervening decade, Alexanderson was employed at both GE and RCA.)

Monocyclic and Polycyclic rectifier and inverter circuits were advanced by Sabbah. (The demonstration high-voltage DC transmission system by GE in 1936 used Monocyclic squares at both terminal stations to protect delicate hot-cathode Thyratrons from damage due to overcurrent.) Series and parallel inverter circuits were pursued for a variety of applications. Sabbah devoted much of his time to series inverter applications, particularly for applications of high-frequency induction heating. Morack worked on parallel inverters for applications that included electric refrigeration. GE introduced the Monitor top refrigerator in 1924. It required AC power to operate its hermetically sealed compressor drive motor. In 1930, several U.S. cities still used DC electric power distribution within their so-called "Edison districts." There was a major market to be served, requiring some means of inverting DC into AC but in small individual blocks of power. The parallel inverter held much promise for this application. Ultimately, the application went to small rotary converters made for that purpose.

In 1933, Joe Slepian at Westinghouse discovered the principle of the "Ignitron." The Ignitron used a pooled-cathode mercury-arc rectifier with silicon-carbide igniter (gate) to initiate conduction. This overcame previous limitations in current density associated with hot-cathode Thyratrons and opened the field to larger-scale applications. In the 1930s, Joe Slepian and David Prince were noted for their "Great Debates," which were held annually at the AIEE. They debated arc-physics and related phenomena, but that story is for a different time.

Although the inverter was developed and demonstrated during the 1930s, its full potential was not realized due to limitations in available rectifier devices. Both the Thyratron and the Ignitron were subject to prolonged recovery times, necessary to regain dielectric capability in the region of the arc. As a result, they were subject to electrical faults, described as "arc-back" and "shoot-through." They were also sensitive to ambient temperature, orientation, and mechanical vibration. Most large-scale inverters produced in the 1930s and 1940s used natural commutation to avoid problems with dielectric recovery time.

Introduction of the thyristor (GE engineers called it the "Silicon Controlled Rectifier" or SCR) in 1957 was the major step forward that truly opened the field to mass applications of power electronics and, in particular, use of forced-commutated inverters. Early applications (1960) include textile fiber spinning, primarily associated with production of nylon.

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—*Edward L. Owen*

For More Information

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