On a Future for Power Electronics

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(*Invited Paper)*

***Abstract*— This paper presents a historical and philosophical perspective on a possible future for power electronics. Technologies have specific life cycles that are driven by internal innovation, subsequently reaching maturity. Power electronics appears to be a much more complex case, functioning as an enabling technology spanning an enormous range of power levels, functions and applications. Power electronics is also divided into many constituent technologies. Till now, the development of power electronics has been driven chiefly by internal semiconductor technology and converter circuit technology, approaching maturity in its internally set metrics, such as efficiency. This paper examines critically the fundamental functions found in electronic energy processing, the constituent technologies comprising power electronics, and the power electronics technology space in light of the internal driving philosophy of power electronics and its historical development. It is finally concluded that, although approaching the limits of its internal metrics indicates internal maturity, the external constituent technologies of packaging, manufacturing, electromagnetic and physical impact, and converter control technology still present remarkable opportunities for development. As power electronics is an enabling technology, its development, together with internal developments, such as wide bandgap semiconductors, will be driven externally by applications in the future.**

***Index Terms*— Future of power electronics.**

I. Introduction

When attempting to construct a possible future for power electronics, different approaches are possible. In this paper, we take a historical and philosophical perspective from the outside. This paper first shows the motivations for this approach in Section II, looks at the historical development in Section III, and examines the present state of the art in power electronics in Section IV. To facilitate this discussion, fundamental internal functions for power electronics are suggested, and the entire field of power electronics technology is divided into a series of interrelated constituent technologies. Section V discusses the examples of emerging applications and technologies in the field of power supplies to illustrate how they are driving the development of the constituent technologies of power electronics. Section VI examines the future driving forces, leading to up to the importance of emerging technologies and applications in driving the envisaged future development of power electronics.

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II. Do We Know Where We Are Heading?

A. Lifetime of Technologies

In our technological society, we have come to accept that technologies come and go. It is, however, extremely important to understand why this happens, how this will happen and when this will happen. Entire industries can disappear when technologies become obsolete, so it is important that appreciable resources be devoted to understand the process of obsolescence. Road-mapping the future of a technology cannot be a mere extrapolation. In this case, it will be based on the assumptions derived from the processes that have been fuelling the development of the technology that is the subject of the investigation. Among other things, a road map needs to consider sufficient history and underlying philosophy driving the technology.

A good example of an inability to anticipate immanent disruptive change in electronic technology is the following. In November 1952, the IRE published a special issue of its proceedings, the Transistor Issue, containing 48 papers on this new technology. In a foreword, McRae, Vice President of Bell Telephone Laboratories, attempts to foresee what impact transistors will have on the economy [1]. In that very same issue, however, we find a two-page advertisement from a large industry—now long extinct—announcing the start of a great new division for full scale manufacture of vacuum tubes to become the leader in research, development, manufacture, and marketing of electronic tubes [2]. Naturally, this does not illustrate that it is futile to speculate about the future of a technology, but serves as an illustration of what can happen if one relies only on extrapolating the present. In the last 50 years, the rate of technology obsolescence has increased remarkably, hence the importance of the history and philosophy underlying each technology in our approaches to gauge the life history of our technologies has become more essential.

One can certainly identify many reasons contributing to engineers being less aware of the aspects that are underlying their technological specialization, but three important reasons appear to be as follows:

1) The emphasis in our education on technology has always been inward and not outward—and as the extent of technological knowledge explodes, this tendency only intensifies.
2) The growing complexity of technological artifacts, systems and processes implies that large teams are involved in development and application, whereas the individual is increasingly busy with smaller and smaller pieces of the whole and has little influence on—and oversight of—the total technology, its lifetime and impact.

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3) Our educational system in engineering/technology appears to have time constants world-wide that exceeds technology lifetimes by many multiples. In many subjects, students are at present still taught the same material as was taught 20 years ago. How much is invested in what they should know 20 years from now?

B. Power Electronics Technology

Power electronics has not escaped from these tendencies, and it is incumbent on us to examine them critically at this stage of the life cycle of our field of expertise. It has been suggested that power electronics is a mature field with limited further scope [3], while recent work has explored in detail the dynamics of power electronics as they approach their limits in terms of technical metrics [4]. These are valuable studies, and we will return to these thoughts later. However, it is necessary to explore where we are going in power electronics against the entire background of the historical and philosophical perspective of this technology, and not to concentrate only on the internal metrics and details of the subject. For example, it has been noted repeatedly that new topologies will not be driving the future development of power electronics [5]–[7]—and indeed history teaches us that the relevant topologies used in industry today are for the larger part older than most of us [8], [9]. Very few new topologies have been adopted, yet our infatuation with new topologies remains. It is an interesting exercise to page through conference proceedings and transactions and read how much work is still devoted to developing these new topologies. Is this a typical reaction of a mature technology that academically reverts into itself by looking only inward? Is the external question of whether this is really relevant in the context of future application suppressed?

C. Road-Mapping Power Electronics

As an attempt to find out where we are heading, road-mapping the different sub-fields within power electronics has been a well-practiced and well-documented activity in our more recent past [4], [10]. From a philosophical point of view, however, internal road-mapping cannot possibly tell us where we are going if the field is becoming mature and nearing the limits of technical achievement. This does not imply that development will stagnate, but rather that further development in aspects not contained within these internal metrics is likely to be driven by external considerations. As an example, a converter with the same efficiency can be packaged by integration in a way that is totally different from traditional packaging, decreasing manufacturing cost and improving form factor that may enable it for a new application. In the future of a mature field, something is going to give, to bend or to disrupt—or new drivers are going to appear. These highly nonlinear events are externally superposed and fall outside an internal frame of reference. An example of a growing external influence is the increasing public awareness that electric energy needs to be saved, and that sustainable electric energy sources need to be introduced. In many programs it is becoming clear that power electronics is the essential technology for achieving this, hence we can expect that this will become a strong external driver in the future, yet we totally lack the capability to quantify the contribution of power electronics [11]. We will return to external drivers in Sections VI-B and C.

III. Notes on the Historical Development of Power Electronics

A. Documented Historical Development

Let us now turn our attention to historical development to see what it teaches us on the underlying philosophy of power electronics. Unfortunately, there is still no work in existence that forms an encyclopaedic reference for the history of electronic energy processing. We have snapshots of the state of power electronics at certain instants in old text books that trace specific historical developments [12]–[14], while studies of certain aspects, such as application to electric machine control [8], [15], or of some historical developments [9], [16], provide some insight into when and where important ideas and technology advances came about. There are two bibliographies that cover the time from 1903 to 1966 [16], [17], while the IEEE have published Special Issues of the Proceedings of the IEEE on aspects of power electronics over the last 50 years in 1967, 1988, 1994, and 2001 [18]–[21]. Collectively, these works [5]–[21] present references to literally thousands of publications, patents, inventions, and applications. This enormous collection of references, when studied chronologically and in detail, will provide the missing encyclopaedic history of power electronics, but such a history still remains to be compiled.

B. Development of a Central Driving Philosophy

We have, however, sufficient information from the fractionally documented history to guide us for the moment. It appears that initially, some characteristics of vacuum tubes were varied to create a continuously variable resistance. Van der Bijl [22] describes the use of thermionic triodes in series or in parallel with the field of dc generators to control the field. The grid was used to operate the tube as an electronically variable resistance. Voorhoeve [23] used diodes for the same purpose and in the same way by changing the heating current and thus the diode's resistance. This use of a time-variable resistance in the circuit was the first step in introducing a nonlinear element to electronically control average power. At that time, all gas discharge tubes that had been in existence since 1903 [16], [17] were in principle uncontrollable, so they could not be used in this way. It was soon apparent that the power level of these methods of using an electronically controllable resistance was severely limited, until Prince [24] came upon the idea to use grid control to switch vacuum triodes and built the first inverter. Langmuir had already invented grid control for gas discharge tubes, but it was not until 1928 that Prince used this as a much improved switch to construct inverters with much higher efficiency. The delay in innovation was caused by the need to first invent the concept of forced commutation to turnoff current [9], [25] in gas discharge devices.

Power electronics had now finally set its course to the philosophy of introducing a switch as a nonlinear element between the electric source and load to control average