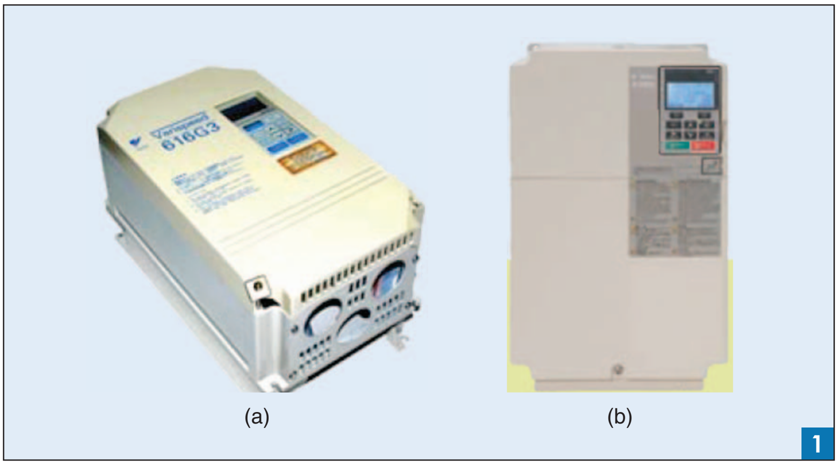
The **Industrial Power Conversion Systems** Department

The Industrial Power Conversion Systems Department (IPCSD) is one of the four departments of the IEEE Industry Applications Society (IAS). Today the IPCSD comprises six technical committees:

- Electric Machines Committee (EMC)
- Industrial Drives Committee (IDC)
- Industrial Power Converters Committee (IPCC)
- Power Electronic Devices and Component Committee (PEDCC)
- Transportation Systems Committee (TSC)
- Renewable and Sustainable Energy Conversion Systems Committee (RSESC).

During the 30th anniversary of the IAS, in 1995, a 100-kW motor drive inverter and various inverter-driven synchronous machine designs were featured as major technical achievements and developments of that time. Since then, the IPCSD has been deeply involved in a rapid evolution of power conversion technologies.

Figure 1 shows a 5.5-kW inverter drive in 1995 and a 30-kW inverter drive in 2014. Their size and weight are nearly the same, but the improvement in the power density is significant. One critical factor is the development of insulated-gate bipolar transistors (IGBTs). The early research on this device [1], [2] paved the way for the first commercial nonlatch-up IGBTs by Toshiba. Since then, IGBTs have played a critical role in the advancement of power conversion technologies.



(a) A Yaskawa G3 VFD, 1995 (200 V ac, 5.5 kW, 14 × 8 × 10 in, 22 lbs.). (b) A Yaskawa A1000 VFD, 2014 (200 V ac, 30 kW, 15.5 × 8.5 × 7.5 in, 22 lbs.).

The following paragraphs briefly discuss the history and accomplishments of each of the six IPCSD technical committees.

Power Electronic Devices and Component Committee

The PEDCC has been in the forefront of testing and modeling power semiconductors for their practical applications in the design of power electronics systems [3], [4]. Since the late 1990s, the testing and evaluation of silicon carbide devices have made tremendous progress: first, with Schottky diodes, second, with junction field-effect transistors, and third, with metal–oxide–semiconductor field-effect transistors (MOSFETs) [5], [6]. In recent years, gallium nitride (GaN) devices have been emerging, and more progress is still expected on their development and deployment. GaN devices have special properties for applications in high-power and high-frequency devices. Over the last two decades, the road map of power electronic switches has been strengthened by a constant improvement of their efficiencies. They became more modular and capable of operating at higher voltages and currents. Noticeable progress has also been achieved in the area of passive components such as super capacitors. Their operation has greatly improved in higher-temperature and harsh environments.

Digital Object Identifier 10.1109/MIAS.2014.2362032
Date of publication: 10 December 2014

Electric Machines Committee

The EMC can trace its origin to the Single-Phase and Fractional-Horsepower Machines Subcommittee of the American Institute of Electrical Engineers (AIEE), one of the two engineering organizations that merged in 1963 to form the IEEE. In 1947, the AIEE undertook a comprehensive reorganization of its committees and subcommittees. One of the technical committees that existed in 1947, the Electric Machinery Committee [7], became the Rotating Machinery Committee in January 1948. The 1948 Rotating Machinery Committee had several new subcommittees, including one called the Single-Phase and Fractional-Horsepower Machines Subcommittee, with a roster of eight members [8]. When the AIEE merged into the IEEE in 1963, the Rotating Machinery Committee and its subcommittees became part of the newly formed Power Group, which was later renamed the IEEE Power Engineering Society (PES, now the Power & Energy Society). In 1984, the subcommittee was granted a request to move from the PES to the IAS [9] and became a subcommittee of the IAS Industrial Drives Committee [10]. In 1986, the subcommittee was renamed EMC when it became one of the technical committees in the IAS IPCSD.

THE IDC HAS ALSO BEEN INVOLVED IN CONTROLS, NOVEL POWER CONVERTER TOPOLOGIES, AND THE USE OF NEW POWER ELECTRONICS DEVICES.

Very few of the records of the period between 1948 and 1984 list the organizational charts of the subcommittees, but the records that do exist show that the Single-Phase and Fractional-Horsepower Machinery Subcommittee was active throughout that period. While the AIEE 1948–1949 directory shows only eight subcommittee members, the 1950–1951 directory shows 14 members and the 1954–1955 directory shows 17 members. The 1966 and 1970 Power Group directories show 17 and 25 members, respectively.

But by the late 1970s, the subcommittee was struggling. The group continued to sponsor papers at the Winter Power Meeting, but, as a subcommittee member once described the situation, they felt like they were meeting in a closet and only talking to the other authors in the session. Several of the members of the subcommittee were familiar with the IAS Annual Meeting and decided that the IAS might be a better venue for them [9]. After two years of negotiations, the subcommittee received approval from PES and IAS to become a subcommittee of the IAS Industrial Drives Committee. In 1984, the subcommittee sponsored two technical sessions at the IAS Annual Meeting with a total of eight papers [11]. While that was a slightly higher number than in previous years, what was most encouraging was the size of the audience, the "land of plenty" as John Oldenkamp, a subcommittee member and former chair, expressed it.

The subcommittee was upgraded to a full IAS technical committee in 1986 with a new name, the IAS EMC. Growth continued and, by 1987, the committee had 60 members and sponsored 20 papers in three sessions at the IAS Annual Meeting. In the 1990s, the committee reached something resembling a steady state. During that period, the committee had approximately 130 members and organized technical sessions with 50–55 total papers in eight sessions during each IAS Annual Meeting.

The situation changed in the 2000s when various international and non-IEEE conferences began to ask the IAS to review some of their papers for publication in *IEEE Transactions on Industry Applications*. Much of this activity was in the technical areas of the EMC. Growth resumed as the committee reviewed more papers from conferences other than the IAS Annual Meeting and the Energy Conversion Conference and Exposition (ECCE). Of particular importance here are the International Conference on Electrical Machines and Systems (ICEMSs) in Asia and the International Conference on Electrical Machines (ICEMs) mostly in Europe, which parallel the ECCE in North America especially in the field of interest of electrical machines. By 2010, the committee was reviewing more papers from cosponsored conferences than from the technical sessions it organized itself. In 2013, the most recent complete year available at the time of writing, the EMC had more than 350 members and had completed reviews of more than 250 papers.

The history of the EMC is one of impressive growth and dynamism. The people who transferred the Single-Phase and Fractional-Horsepower Subcommittee to the IAS in 1984 succeeded not only in reviving the group but also in starting a process that transformed a small subcommittee into one of the largest and most active committees within the IAS.

Industrial Drives Committee

The IDC has mainly been involved in the area of industrial drive applications, which addresses their performance in terms of efficiency, reliability, power density, system compatibility, and cost. The IDC has also been involved in controls, novel power converter topologies, and the use of new power electronics devices. On the controls side, the committee has been interested in the development of efficient, high-bandwidth, and robust control methods.

Industrial Power Converters Committee

The IPCC can trace its origin to the subcommittee on mercury-arc rectifiers under the auspices of the AIEE Committee on Electrical Machinery [12]. The subcommittee transferred to the Committee on Electronics in 1940 before becoming the Committee on Electronic Power Converters in 1947. It went through the following reorganization and name changes:

- Committee on Industrial Power Rectifiers in 1955
- Static Power Converter Committee in 1968
- IPCC in 1989.

Such changes are closely related to the evolution of power conversion technologies. The transition from mercury tubes to semiconductors occurred in the late 1950s and early 1960s. The thyristor-based conversion technologies started their expansion in two waves: first, the naturally commutated converters in the mid-1960s and then the self-commutated converters in the 1970s. As gate turn-off thyristors continued to displace conventional thyristors with commutation circuits in high-power applications, the bipolar junction transistor (BJT)-based converters quickly emerged into the industrial level in the 1980s. MOSFETs of increasing capacity became available. IGBTs, a combination of the bipolar and unipolar transistor technologies, emerged in the mid and late 1980s and quickly became a critical driving force in the power conversion technologies. Continuing the tradition of its predecessors, the IPCC has been greatly involved in this latest wave of evolution. IGBTs enable pulsewidth modulation (PWM) operation [13], [14] for high-bandwidth and high-power industrial applications compared with the earlier BJT- and thyristor-based converters. The space vector PWM techniques and their variations [15]–[17] are adopted to utilize newly acquired advantages. Fundamental current control techniques based on PWM operations are also developed [18]–[23].

The multilevel circuit topologies further extend the application range into the medium-voltage level. The neutral-point-clamped circuit [24] has been widely adopted for wind and solar power systems, high-power motor drives, uninterruptible power supplies (UPSs), and other industrial applications. The modular multilevel converters [25], [26], suitable for an even higher voltage range, also gained significant momentum in the industrial and utility applications.

The industrial applications of the PWM converters technologies quickly gained momentum. Variable-speed drives became ubiquitous. Multilevel converter technologies allowed its expansion into the megawatt range [27]. UPSs were adopted to deliver high quality and high reliability of electric power to critical loads [28]–[30]. Power quality applications, such as harmonic active power filters [31]–[34], voltage sag compensators [35], and reactive power, saw rapid growth.

In the utility level, the renewable energy systems have grown significantly, from a few gigawatts of installed capacity to +100 GW for photovoltaic (PV) and +300 GW in wind with about 50 GW predicted both for wind and PV estimated in 2014. The dramatic power scaling seen in wind turbines and the mass volume production of PV has decreased the cost of energy. The power converters have seen constant cost reductions as well as improved reliability [36]. The integration of renewables also leads to a major evolution of the grid codes. In the beginning, renewable was an energy source, but now it is an active power source that is also reactive during grid faults. As more renewables, alternative resources, and storage methods are being adopted, our utility is gradually moving toward the smart grid future. These demands will pose great challenges and opportunities for the power converter topology and control, and the IPCC will continue to strive for new innovations.

> GaN DEVICES HAVE SPECIAL PROPERTIES FOR APPLICATIONS IN HIGH-POWER AND HIGH-FREQUENCY DEVICES.

Transportation Systems Committee

The TSC was established by the IAS Board at the Annual Meeting in October 2011, based on a motion by Giovanna Oriti, the IPCSD chair [37]. The TSC is responsible for all matters within the scope of the IAS in which the emphasis or dominant factor specifically relates to the electrification of the transportation industry, including components, systems, and infrastructure, and encompassing all modes of transportation for people and goods, including automotive, off road, ship, trains, and aircraft.

The founding officers were Iqbal Husain (chair, NCSU, United States), Ayman El-Refaie (vice chair, conferences, GE, United States), Burak Ozpineci (vice chair, papers, ORNL, United States), and Mohammad Islam (secretary, Nexteer, United States). A steering committee was also put together to help the fledging committee fully develop (Bruno Lequesne, Eaton, United States; Giovanna Oriti, Naval Postgraduate School, United States; Tomy Sebastian, Nexteer, United States; Avoki Omekanda, General Motors, United States; Uday Deshpande, General Dynamics, United States).

The committee activities are deeply rooted in the article of the other four committees of the IPCSD, particularly at the IAS Annual Meeting and the ECCE. For years, these conferences regularly held sessions and tracks on the subject. The transportation industry has often been represented on the IAS Board at the highest level. More recently, however, with renewed interest in hybrid systems, electric vehicles, and transportation electrification in general, and the start of new conferences and pan-IEEE activities on the subject, it was clear that the community needed a home of its own.

Aside from its continuing activities at the ECCE, the TSC is actively involved with the IEEE Transportation Electrification Conference (ITEC), which started in North America in 2012 (under the leadership of Ali Emadi, McMaster University, Canada) and in Asia in Beijing, China in 2014 (led by Longya Xu, Ohio State University). Plans are also under way for India at a later date, in cooperation with the SAE India. Other symposia and conferences are also sponsored or technically cosponsored, such as the International Electric Vehicle Conference (IEVC), the Electric Ship Technologies Symposium (ESTC), and the Ecological Vehicles Renewable Energies Conference (EVER). ITEC 2014 in Dearborn, Michigan, saw the presentation of the first IEEE Transportation Technologies Awards to IAS Past President Linos Jacovides (1990).

Aside from its traditional involvement with both *IEEE Transactions on Industry Applications* and *IEEE Industry Applications Magazine,* the committee is actively supporting *IEEE Transactions on Transportation Electrification*, slated to start in 2015, and *IEEE Electrification Magazine*.

In 2011, the IEEE launched an initiative aimed at developing a home for all matters related to the subject within the IEEE. The initiative developed a number of new products, including a portal (http://electricvehicle.ieee.org/), conferences such as the IEVC, and formal interactions with the SAE and other organizations particularly around standards. In 2014, the initiative transitioned away from an IEEE-based and funded group to one operated by a consortium of societies. The TSC is expected to be fully involved with the new community that will emerge from the current transition discussions. More broadly, the new committee serves as a partner with other societies and entities involved in transportation.

A MAIN OBJECTIVE OF THE RESESC IS TO INCREASE THE MEMBERSHIP BY ENGAGING PROFESSIONALS IN THE FIELD OF RENEWABLE AND SUSTAINABLE ENERGY IN ITS ACTIVITIES.

It is interesting to note that early IAS rosters (the first roster and that in 1974) mention a Land Transportation Committee and a Marine Transportation Committee. In 1984, the Marine Transportation Committee was part of the General Industries Department [38]. It was moved to the Standards Department in 1991 [39], then in 1997 to the PCIC, where it is to this day a very active, standard-generating subcommittee (recently involved with ship-to-shore standards). It meets every year at the PCIC conference.

The Land Transportation Committee was focused on large systems, such as trains and mine haulage vehicles [40]. It co-organized a railroad conference with the American Society of Mechanical Engineers and had sessions at the IAS Annual Meeting as of 1984 [38], [40], [41]. As of 1989 [42] and to this day, the railroad conference has been very active, cosponsored on behalf of the IEEE by the Land Transportation Division of the IEEE Vehicular Technology Society (VTS). We presume but have not confirmed that this committee moved to the VTS around 1986.

Renewable and Sustainable Energy Conversion Systems Committee

The RSESC was established and approved at the IAS Quarterly Executive Meeting in the fall of 2011. This committee is responsible for all matters within the scope of the IAS in which the emphasis or dominant factor specifically relates to the design, analysis, manufacture and use of electric devices and systems for renewable and sustainable energy conversion industrial applications. Topics include, but are not limited to, electric generators and drives for wind turbines, ocean/marine, and other renewable and sustainable energy harvesting systems, photovoltaics, energy storage and microgrid devices, and associated electrical energy conversion systems.

A main objective of the RESESC is to increase the membership of the IEEE in general and of the IAS in particular by engaging professionals working or having an interest in the field of renewable and sustainable energy in its activities. This objective is achieved in synergy with supporting the ECCE and *IEEE Transactions on Industry Applications* efforts. The inaugural executive committee for the RSESC included Dan M. Ionel (United States), chair, David G. Dorrell (Australia), vice chair and TPC, Pedro Rodriguez (Spain), vice chair, and Yilmaz Sozer (United States), secretary. The first annual meeting of the committee was held during ECCE 2012 in Raleigh, North Carolina, and was attended by more than 80 people. For ECCE 2012 and 2013, the committee contributed directly to the organization of Tracks A and B, which were the largest, and also organized rap and special sessions. The committee established the connections and IAS sponsorship for international conferences such as ICERA 2012 in Nagasaki, the International Conference on Sustainable Energy Technologies 2012 in Kathmandu, EVER 2013 in Monaco, the 2013 International Conference on Power Engineering, Energy and Electrical Drives in Istanbul, the 2014 IEEE Symposium on Power Electronics and Machines in Wind Applications in Milwaukee, Wisconsin, and ICERA 2014 in Milwaukee. The inaugural round of best paper awards were presented during ECCE 2013 to authors from the United States, China, and Taiwan on topics of diagnostics of wind turbine gearboxes, photovoltaic inverters, and dc distribution systems for wind power [43]–[45].

Acknowledgment

We would like to thank the officers of all IPCSD Committees for their contribution to this column.

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