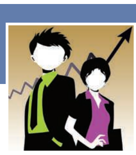

by Hani Vahedi, Kamal Al-Hadad, Anton Sysoev, Vladimir Istomin, Monika Dabas, Stan Valtchev, Wenbin Dai, and Marek Jasinski

The IEEE IES: An Interdisciplinary Family of Mentors, Young Professionals, and Students

If we look at the world today, we may wonder how technology is important for us. Is there any discipline that could cover and join with current trends? At the IEEE Industrial Electronics Society (IES) website [1], one can read the following:

> The Industrial Electronics Society through its members encompasses a diverse range of technical activities devoted to the application of electronics and electrical sciences for the enhancement of industrial and manufacturing processes. These technical activities address the latest developments in intelligent and computer control systems, robotics, factory communications and automation, flexible manufacturing, data acquisition and signal processing, vision systems, and power electronics. The Society continually updates its program of technical activities to meet the needs of modern industry.
>
> The vision of the IES is to advance global prosperity by fostering technological innovation, enabling members' careers and promoting community worldwide. The IES promotes the engineering process of creating, developing, integrating, sharing, and applying knowledge about electro- and information technologies and sciences for the benefit of humanity and the profession.

The history of the IES can be viewed at [2]. We should remember its origins. Moreover, it is important to use the experiences of mentors, students, and young professionals to grow and expand research opportunities.

Invitation for Contributions to the Column, YouTube Channel, and Media Center

We would like to invite all mentors, students, and young professionals to contribute to this column. Please share information about your projects, industrial experience, educational processes, and so forth as we are open to your subject proposals. We know that you know best how to describe your activities in an interesting and attractive way. It is worth pointing out that you should try to stress your field of mentorship, study, or experience and show how the synergy between academia and industry, in your case, works. In addition, it is a good idea to prepare some multimedia materials and provide your submission proposal for possible publication in IES e-channels.

Close Relations With Industry

Electrical engineering, electronics automation, and information technology (as an applied science) have strong links to the industry, and the industry is our target. When we are searching for a field of study, we always consider in which industry field we would work after the study. Today, the situation is interesting. More and more industrial partners of many universities would like to take part in the educational process. It is not easy but it is possible, and were this action to be implemented properly, the industry would obtain well-experienced workers just after study. Moreover, some branches of costly R&D departments could be acquired from universities, examples of which can be found in Denmark, Germany, the United States, and so on.

Cooperation With Sister Societies

IES fields are widespread thanks to its excellent sister Societies within IEEE:

- IEEE Power and Energy Society
- IEEE Industry Applications Society (IAS)
- IEEE Power Electronics Society
- IEEE Dielectrics and Electrical Insulation Society.

Many IES members have a membership not only in the IES but also in other IEEE Societies. We are quite an interdisciplinary team. For those who are interested, there is an IEEE Young Professionals Affinity Group that links all its members from IEEE.

Open Journals

If you are thinking about publication, please consider IEEE open journals as it is an excellent way to access the widest-possible audience. A good opportunity is to submit an article for publication in *IEEE Open Journal of the*

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Industrial Electronics Society; however, if you prefer to stay with the traditional form of publication and your subject is multidisciplinary, you may opt for *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*.

E-Mobility as a Good Example of an Interdisciplinary Area

Coming back to the idea of how technology is important to us, just look at the example of e-mobility. Electrical, automated massive transportation development is like a trigger for all industry branches. The electrical grid, steel and heavy industry, automobiles, energy storage, charging technology, robotics, control robustness, data acquisition and processing, energy conversion, telecommunication, distributed energy sources, society, health and psychology, and so on will be transformed into a more intelligent (artificially intelligent) form. It is important to provide an interdisciplinary platform for discussion from the very beginning. This could compensate for the differences and misunderstandings among specialists from different fields.

Conferences and Virtual Events

It is interesting to observe the world during the COVID-19 pandemic. It is evident that after this time, our society will have a wider focus on reality. New forms of virtual events and communication has been started and evaluated. It is our pleasure to take an active part in this process, and we would like to promote your work. Your scientific activities, education processes, and, finally, the implementation of your ideas in industry is our focus. We have 70 years of experience. It is worthwhile to quote Stanislaw Staszic [4]: Skills are merely a vain invention, just a folly of the brain or idle fun so long as they are not used for the benefit of nations.

Therefore, we shall focus on others and how we would help and support them through our daily work. Some examples have been published already in previous issues of *IEEE Industrial Electronics Magazine* [5]. Thank you all for your outstanding hard work. While reading about your daily progress, we are keeping in mind a quote from Albert Einstein [6]:

> A hundred times every day I remind myself that my inner and outer life are based on the labors of other men, living and dead, and that I must exert myself in order to give in the same measure as I have received and am still receiving.

The Packed U-Cell Converter: A Technology Transfer From Academia to Industry

Industrial Consideration of Multilevel Converters

Power electronics inverters are used in many power industries, particularly renewable energy conversion and electrified transportation. Due to the unbelievably fast development of semiconductor devices such as silicon carbide and gallium nitride, the size and cost of market inverters are getting much smaller in recent years. On the other hand, the same thing is happening to the digital signal processor microcontrollers that facilitate implementing digital controllers for those very same power electronics inverters.

Multilevel inverter technology has become mature in the last decade and is replacing the conventional two-level, six-switch, three-phase converter in high-power applications. In addition, single-phase multilevel topologies can be seen in the market for medium-power ratings [7]. Although too many topologies are reported every day, a few of them could find their way to the industry. The main issue with most of the introduced topologies is the high number of components, especially those using more than one isolated dc source. There are some specific differences between single- and multiple-dc-source multilevel inverter topologies that limit the application of multiple-dc-source inverters in power systems. We discuss these limitations separately, based on the topology and the associated controller approach [8].

From a topology point of view, multiple-dc-source inverters need more than one isolated dc supply. Therefore, they will not be cost-effective and small sized because an isolated dc supply is made up of a transformer and a diode bridge or, it could be a battery or photovoltaics (PVs) panel, as shown in Figure 1. Consequently, multiple-dc-source topologies have at least one more supply than does a single-dc-source one, which means an undesired size and cost. The most popular multilevel inverter with a multiple-dc source is a cascaded H-bridge (CHB) [see Figure 2(a)], which is currently used in very high-power motor drives. The main advantages of CHBs are their modularity and their identical voltage rating of switches due to the use of equal dc sources.

Many other multiple-dc-source topologies have been published, but they suffer from an unequal voltage rating of dc supplies and switches—the main reason why they have not received more attention from industry. A fair comparison among CHBs and all of the aforementioned multiple-dc-source multilevel inverters when considering an equal voltage rating of components reveals the fact that CHBs are still the best type of inverter with an optimum number of components due to their modularity and identical voltage rating in each cell.

Neutral point clamped (NPC), flying capacitor (FC), T3, and active NPC (ANPC) are the most attractive

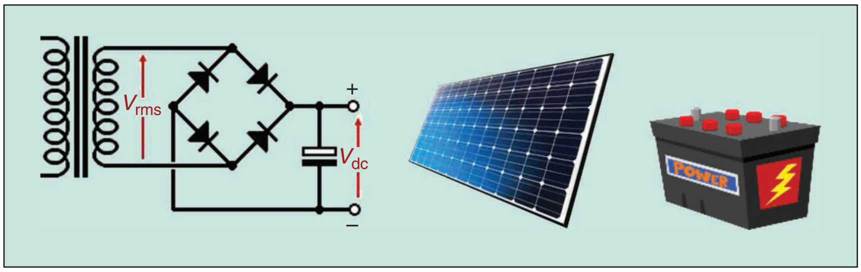

FIGURE 1 – Examples of isolated DC sources.

single-dc-source topologies in which some FCs (auxiliary ones) are used to produce more voltage levels at the output. The main challenge of those configurations is their voltage balancing of auxiliary capacitors, which could be performed through redundant switching states, external controllers, or additional circuits. The most important feature of those topologies is that they need only one isolated dc source, so the same connection used for two-level inverters could be used for them. All PV panels or batteries will be arranged to deliver maximum power to one point of coupling at the dc bus of single-dc-source multilevel inverters. Another concern with multiple-dc-source configurations is their power sharing among feeders. An unbalanced power sharing causes undesirable power losses and malfunctions.

A cascaded control consisting of a current and a voltage loop is required for most power converters applications. Focusing on grid-connected ones, such as PV systems, the dc bus should be also regulated by injecting the voltage error into the current reference. Such a scheme, as displayed in Figure 2(b), requires numerous voltage loops and, consequently, voltage proportional-integral regulators for multiple-dc-source topologies.

Moreover, implementing a power-balancing unit is inevitable to share the appropriate amount of power between sources. Furthermore, injecting all of the voltage errors into only one single current reference cannot ensure the proper distribution of the active power among dc links to keep the capacitors' voltages fixed. This issue also exists in single-dc-source inverters in which there are no redundant switching states to balance the auxiliary capacitors' voltages.

In conclusion, a single-dc-source inverter in which the auxiliary capacitors are controlled through switching states without adding extra linear/nonlinear regulators and complexity to the system is desired. Such a topology can be installed in all power system applications where the two-level ones are already operating. Therefore, the input dc side and output ac side do not need to be modified. Moreover, the controller remains the same because only a single dc link should be regulated, and the error signal goes into the reference current. However, the modulation block should be replaced by a multilevel switching technique with integrated voltage balancing using redundant switching states.

The PUC5 and Technology Transfer

The path from an idea—as innovative as it may be—to a successful commercial product is a long and difficult one. PUC5 commercialization is a good example. It can be analyzed in two different categories: academia and industry.

For the academic environment, it should be noted that in the field of power electronics, the simplicity of a new technology is one of the most important features that attract industry. Any improvements involving a complex or costly solution will not impress the market. On the other hand, a simple design with reliable performance that reduces the size, cost, loss, or maintenance for an organization would be appreciated and find its way to industry. Full-bridge inverters are used widely in industry due to their simple and well-known structure and operation. Accordingly, the CHB multilevel topology is popular in very high-power applications due to its simplicity and modularity. Other multilevel inverter topologies in the market are NPC, ANPC, and T3. They all need voltage control for their dc link capacitors while using a single dc source like a full bridge. As long as the voltage-balancing technique is integrated into the switching pattern, they would not need to use an external complicated controller.

PUC topology was invented as a seven-level inverter with a fewest-possible number of switches (only six) [9]. Dr. Hani Vahedi's Ph.D. project was on multilevel inverters, and he began working on PUC topology (see Figure 3). Soon he realized that PUC inverters could not attract companies to invest due to a lack of simplicity in their control. The seven-level topology needs a complex voltage controller, which limits its reliability and easy

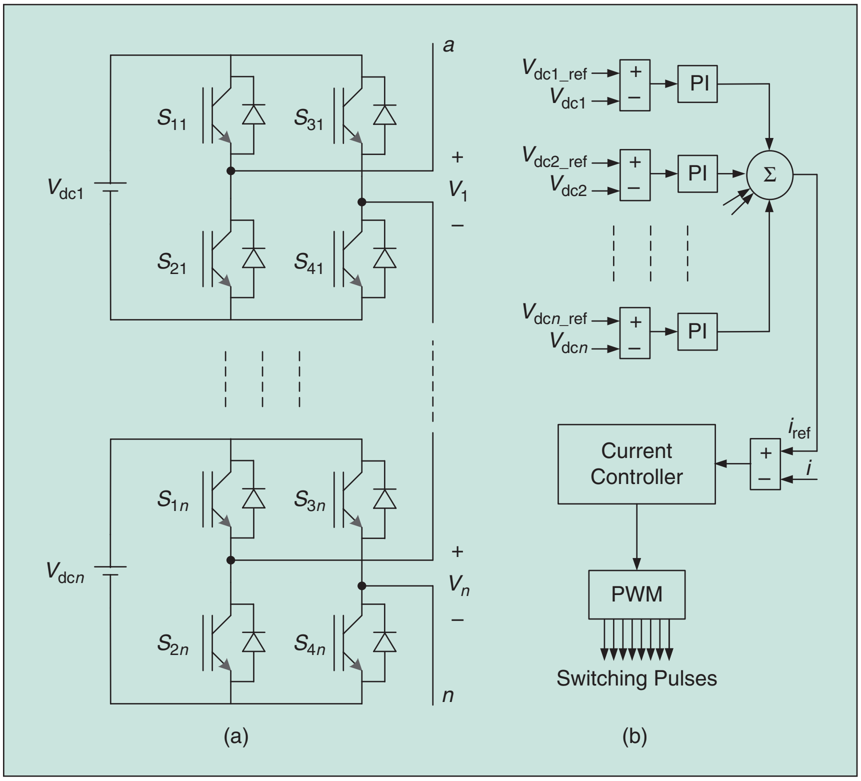

FIGURE 2 – Multiple-dc-source inverters. (a) A CHB and (b) its corresponding controller. PI: proportional-integral; PWM: pulsewidth modulation.

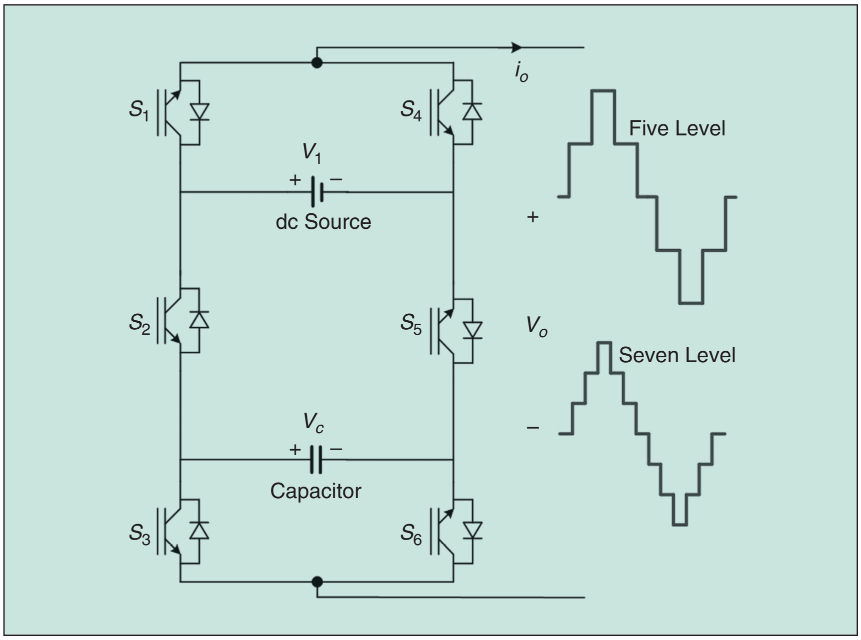

FIGURE 3 — Vahedi's PUC5 inverter.

TABLE 1 — ALL OF THE POSSIBLE SWITCHING STATES OF A PUC5 INVERTER.

STATES	S_1	S_2	S_3	OUTPUT VOLTAGE	V_L	EFFECT ON AUXILIARY CAP
1	1	0	0	V_1	+2E	No effect
2	1	0	1	V_1–V_2	+E	Charging
3	1	1	0	V_2	+E	Discharging
4	1	1	1	0	0	No effect
5	0	0	0	0	0	No effect
6	0	0	1	–V_2	–E	Discharging
7	0	1	0	V_2–V_1	–E	Charging
8	0	1	1	–V_1	–2E	No effect

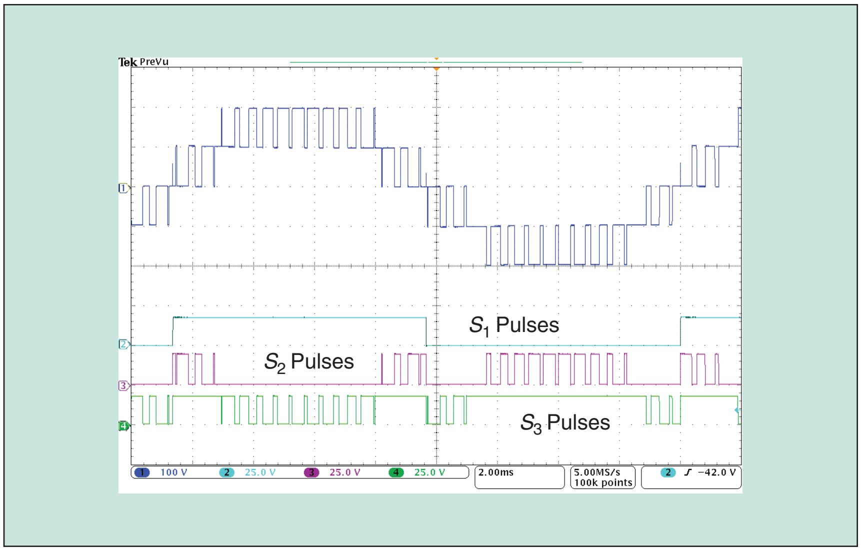

FIGURE 4 – A PUC5 inverter switching pulses.

design/operation for commercialization. Moreover, there were no redundancies in the switching states. As a solution, the PUC5 was introduced with a fewer number of levels (generating fie-level voltage), which provides some redundant switching states that facilitate balancing the capacitor voltage without requiring external controllers [10]. The voltage controller of the auxiliary capacitor was integrated into the switching algorithm using those redundancies. Furthermore, it has a fault-tolerant structure with added reliability while using only two more switches rather than the full bridge. On the other hand, it inherently generates five-level output voltage using low-harmonic contents and features a single-dc source. All the standard controllers for different applications can be applied to this topology with the existing implementation procedure on industry-rated microcontrollers.

It is a single-dc-source topology that generates five identical voltage levels. The switching states and their effects on the capacitor voltage are listed in Table 1, where $V_{dc} = 2E$ and $V_c = E$. The main advantage of PUC5 topology is that it has redundant switching states, making it a single-dc source. The redundant switching states ease voltage balancing without the use of external controllers. In addition to the switching states being useful for voltage balancing, the states of four and five can be considered to reduce the switching frequency effectively. Moreover, each pair of switches is fired complimentarily, and the two upper switches work at line frequency, as shown in Figure 4.

A sensor-less voltage-balancing technique was proposed for the PUC5 but suffers from a large capacitor in its structure [11]. As a result, a voltage sensor was used to switch among redundant states at the speed of the switching frequency and to maintain the capacitor voltage at the half of the V_1 with a very low voltage ripple. Consequently, it reduces the required capacitance significantly, which can be a film capacitor.

All of these characteristics make the PUC5 an interesting topology for companies that are considering a new multilevel topology for industrial applications and the power electronics market. During his Ph.D. studies, Vahedi was able to publish most of his research outcomes about PUC5 topology for grid-connected, standalone, inverter, and rectifier applications (see Figure 5). They also protected that technology with a U.S. patent (filed in 2014, published in 2016, and granted in 2018) [10] and were finally able to convince industry to invest. In 2016, Ossiaco Inc. (a Montreal-based company) [12] signed an exclusive agreement with Ecole de Technologie Superieure to commercialize the PUC5 converter as the core technology for their residential bidirectional electric vehicle (EV) charger called *dcbel* [13] (see Figures 6 and 7). That product can charge EVs and also discharge them to the home or grid (that is, vehicle to home or vehicle to grid) thanks to the bidirectional operation of the PUC5 converter. Moreover, it can have PV panels or batteries as a source and deliver green energy to the home or grid.

It was long and stressful but also exciting and educational for him to work on cutting-edge technology and develop it in academia for transfer to industry. He was enjoying his hands-on experiences in the lab while teamed with another student, Philippe-Alexandre Labbe, who was earning his master's degree (see Figure 8). They were both working on a PUC5 inverter under the supervision of Prof. Kamal Al-Haddad at The École de technologie supérieure. Interestingly, Vahedi is currently working on his own product and designing it for people so that they can improve their experience with power electronics converters, and especially EVs and PV applications.

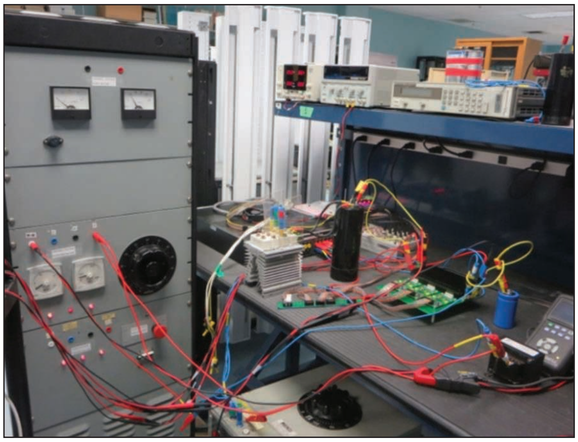

FIGURE 5 – An experimental setup of a PUC5 inverter in The Power Electronics and Industrial Control Research Group lab.

FIGURE 6 – The Ossiaco Inc. team preparing for 2019 dcbel demo event.

FIGURE 7 – dcbel, the first bidirectional EV charger, PV inverter with blackout power capability, and home energy operating system. (dcbel 2018 prototype shown in live testing.)

It Is Not Easy to Be the First: Cooperation Among Student Scientific Activities and Industrial Applications

The IEEE IES Lipetsk State Technical University Student Branch Chapter (SBC) was established on 20 May 2020. The idea to organize this chapter originated in November 2019 when IEEE Student Members actively participated in organizing the first International Conference on Control Systems, Mathematical Modeling, Automation and Energy Efficiency (SUMMA). It is noteworthy that this scientific event was supported by the V.A. Trapeznikov Institute of Control Sciences Russian Academy of Sciences, a long-term scientific partner of Lipetsk State Technical University. For many years, students have participated in and won Russian contests for young researchers in control theory and its applications as well as have taken part in conferences for young scientists held by the Trapeznikov Institute. All of this was made possible through the cooperation, support, and teamwork of the scientific schools at the university.

On 30 July 2020, a joint Chapter of the IAS and IES was established at Lipetsk State Technical University. This chapter became a milestone for two reasons: It was 300th IAS SBC worldwide and the first IAS SBC in Russia. At the moment, the Chapter consists of 16 young researchers, including bachelor's, master's, and postgraduate students of the departments of Applied Mathematics, Informatics, Automated Control Systems, Electric Drives, and Electrical Equipment. The members actively take part in various scientific competitions, championships, forums, hackathons, and conferences and prepare the results of their studies to be published in industry periodicals.

Lipetsk State Technical University is developing a number of original fields that relate to modern scientific tendencies. Prof. Pavel Saraev, Prof. Anatoly Pogodaev, Prof. Semen Blyumin, and Prof. Yuri Kudinov are the leading researchers at Lipetsk State Technical University in the field of modern information technologies and are increasing the efficiency of automated systems for managing production and product quality. Their studies, as well as those of their students, are supported by the Russian Scientific Organization and Russian Foundation for Basic Research and have been implemented in industrial companies such as Novolipetsk Steel (see Figure 9).

For example, our SBC webmaster, Ph.D. student Alexey Tyurin, manages the "Digital Assistant for Setting the Steel Casting Temperature" project. Tyurin successfully developed a model that predicts temperature drops at the production site of the casting steel unit that operates during production. The model is based on a gradient-boosting algorithm that is applied for decision trees. Feedback from the production revealed many opportunities to further improve the quality of the model.

A similar example is the "Modeling of Thermal Mode in Steel Rolling" study, conducted by Monica Dabas. Software has been developed that includes several mathematical models of the temperature distribution along the thickness of the strip and working rolls that calculate the thermal conditions of the hot rolling mill. The models inside this system are defined by the current zone (the rolling and interstand gaps and the cooling zone on the surface of the roll). Information about the construction and settings of the nozzles and the roll antipeeling systems is used. At the moment, the direction of further development awaits the validation of the received models and the expansion of software functionality (Figure 10).

Prof. Viktor Meshcheryakov is the founder of the Energy-Saving Structures of Power Systems scientific school. This school is engaged in the development of energy-efficient electrical and electric drive complexes and systems. Doctorate student Aleksey Evseev is the author of the project "Electric Arc Plasma Installation With Control Information-Measuring System". The plasma torch is designed for the utilization of the carbon-containing wastes and slurries found in processing industries. The existing electric-arc plasma systems have disadvantages; for example, the complexity of both the design and the regulation of the installation performance that produces the plasma. The peculiarity of the proposed plasma torch is the effect of an external electromagnetic field on the arc; this allows the arc to be pulled out of the tubular housing.

FIGURE 8 – The PUC5 team (from left): Labbe (master student), Al-Haddad (professor and supervisor), and Vahedi (Ph.D. student) worked on a PUC5 inverter at ETS.

FIGURE 9 – Students tour the Novolipetsk Steel facility.

FIGURE 10 – A rolling mill machine.

The authorities at Lipetsk State Technical University strongly support the intentions of students to be a part of IEEE. The faculty of the Automation and Computer Science Department, the basis upon which the SBC was formed, unites the students training in the priority areas of the development of science and technology in the Russian Federation.

On 10 September 2020, the SteelCase team won the seventh international engineering championship CASE-IN (Figure 11). The contest's jury noted the innovative solution of the "Modernization of Aluminum Production Technology for Obtaining Ingots With a Reduced Content of Manganese and Reducing the Harmful Impact on the Environment" case, which was presented by students from Lipetsk State Technical University. The members of the SteelCase team suggested using an innovative material for lining buckets: nanoxylene. This solution was the result of the collaboration between students and Novolipetsk Steel company.

Novolipetsk Steel is a landmark of Lipetsk, which is rightly called the *city of metallurgists*. Metallurgical production at Novolipetsk Steel occurs using a *full cycle*, meaning that all of the production facilities necessary for iron ore to pass through all the technological stages and turn into the final metallurgical product—cold, rolled steel—are located on the industrial site of the plant. Modern, complex high-tech production requires solutions that are scientifically proven to be effective. Lipetsk State Technical University is one of the main strategic partners of the Novolipetsk Steel Company Group (Figure 12), both in the fields of training qualified staff and conducting applied scientific

FIGURE 11 — Members of SteelCase, the winning team at CASE-IN, are presented with their awards (Lipetsk State Technical University, September 2020).


FIGURE 12 — The Novolipetsk Steel facility in Lipetsk, Russia.

FIGURE 13 — The opening ceremony of the SUMMA 2020 conference: (from left) Associate Prof. Anton Sysoev (the local organizing committee), Associate Prof. Alexander Galkin (the local organizing committee), and Prof. Pavel Saraev (general cochair).

research. The history of the university's scientific schools' establishment and their further development is inseparably connected with the development of the plant and covers all of the production stages.

From 11 to 13 November 2020, the second SUMMA conference was held with the joint effort of the IES Lipetsk State Technical University SBC and the university. The SBC expresses its gratitude to the IAS for its support and the opportunity to organize a conference in a virtual format to ensure the safety of participants during the COVID-19 pandemic (see Figure 13).

Our utmost priority is expanding the list of participants to include students in advancing technology for humanity—the world of IEEE.

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