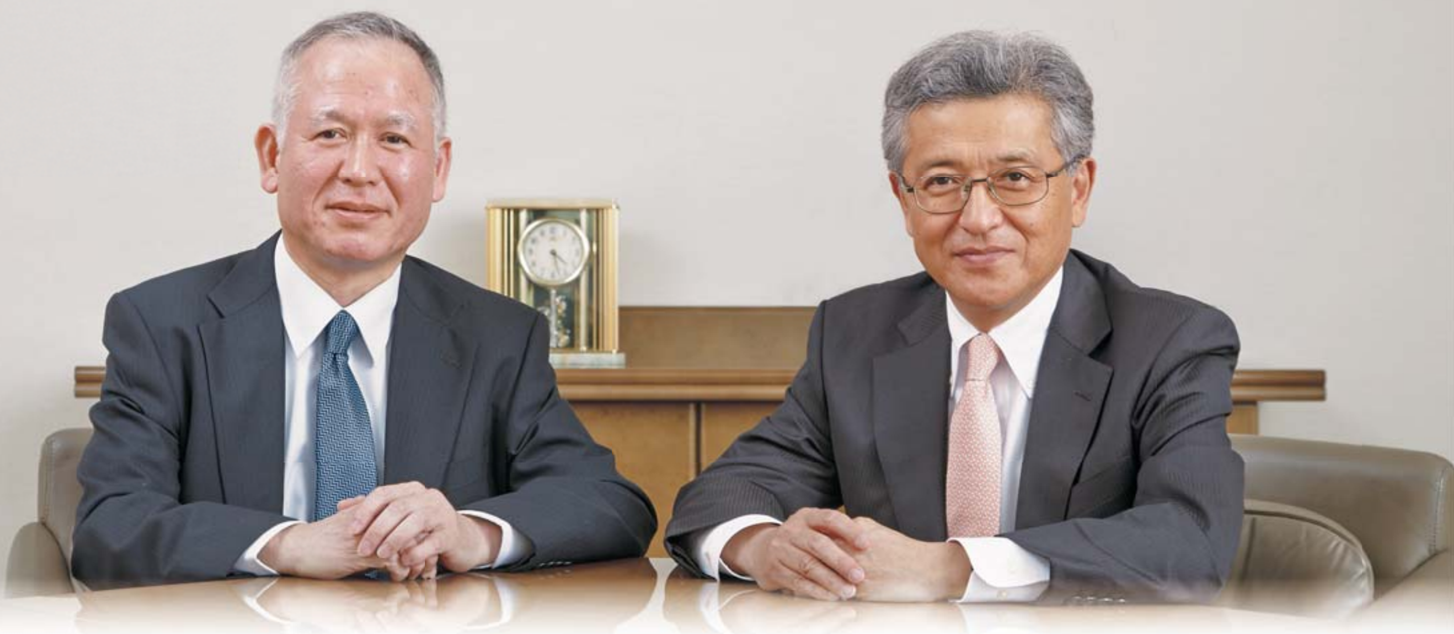
A Challenge to Energy Innovation Through Power Electronics

Expanding Applications of Power Electronics via Device Innovation



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The emergence of SiC power devices has enabled power electronics to be applied to fields that were difficult in the past. Where will the future of power electronics lead us? What can we expect from Fuji Electric that pursues to create a sustainable society through the use of energy technology? We had the special opportunity to meet with one of the pioneers of power electronics, Professor Dr. Akagi, Tokyo Institute of Technology. He sat down with Dr. Eguchi, Corporate General Manager of Corporate R&D Headquarters at Fuji Electric, to discuss their opinions regarding the possibilities and issues surrounding power electronics.

Power Electronics is Fuji Electric's Core Technology

Eguchi: We have worked with Professor Akagi, one of the pioneers of power electronics, on several joint research projects and received useful advice. I would first like to express my appreciation to Professor Akagi again. Today I would like to hear your broad-minded opinions so that we can discuss the development of power electronics and contribute to the future of Fuji Electric.

Fuji Electric was established 91 years ago in 1923 on the joint funding of Furukawa Electric Co., Ltd. and the German company Siemens AG (which is pronounced “Jiemens” in German). Fuji Electric was named after the “Fu” in Furukawa and “Ji” in Jiemens.

Fuji Electric had originally developed as a company that manufactured heavy electric equipment such as motors and transformers. In 1959, we started the manufacture of silicon diodes as power semiconductor devices (power devices), and then later we began manufacturing power electronics equipment such as rectifiers and inverters.

As we look back on the history of Fuji Electric, we can see that power electronics has always been a core technology of our business.

Fuji Electric will continue to manufacture environmentally-friendly and highly value-added products that make the most effective use of energy in its pursuit to realize a safe and secure sustainable society. In order to achieve this, we are aiming to provide optimal solutions integrating power devices that characterize Fuji Electric into power electronics technology that uses the power devices (e.g. power converters) as the core, combined with various surrounding technologies.

Professor Akagi, when did you first start working in the power electronics field?

Akagi: In 1957, the American company, General Electric became the first company to manufacture thyristors. I think that it would be correct to say that this was the practical start of the power electronics field.

I started doing research on power electronics in my graduation work during my fourth year as an electrical engineering student (in 1973). As an undergraduate and graduate student, I did research in the areas of a line-commutated cycloconverter and a forced commutation circuit, using thyristors. After becoming a university faculty member, I started working hands-on with nearly all types of power devices including the now obsolete static induction transistor (SIT). I have been dedicated to the power electronics field for 41 years.

When Likened to the Human Body, Power Electronics is the Muscle

Eguchi: You have always been at the cutting edge of power electronics in the long history. I have also been engaged in power electronics since my fourth year at a university in 1977 and have also devoted myself to power electronics since entering the workforce. During that time, power devices underwent dizzying changes.

Recently, the term "power electronics" is being heard more often. So, how would you respond if you were asked "What is power electronics?"

Akagi: Although it is a bit difficult to explain to non-technical people, I would say that for researchers and engineers, with various different specialties in electrical and electronic engineering, power electronics is an applied technology with power conversion technologies using power devices placed at the core, and is being practically employed in various applications such as those for motor drives, various power supplies and power system equipment. Since inverter-based air conditioners began to appear on the market in the early 1980s, the term "inverter" has been becoming more familiar to people, but power electronics covers a much larger range of technologies, which also includes inverters.

It might be easier to give an example such as that of photovoltaic power generation. Since photovoltaic cells generate DC power, connecting the output terminals to 50Hz or 60Hz power systems requires DC to AC power conversion. Power electronics is the key technology that makes this power conversion highly efficient.

Eguchi: Electronic circuits such as microcomputers and LSIs are used to control electrical signals, whereas power electronics to control electrical energy.

Akagi: Yes, that is right. If we liken the technologies to the human body, a computer is like the brain while power electronics is the muscle.

Eguchi: That is an easy way to think about it.

These days power electronics is used in many different products. Wouldn't you agree that it can be found in most home electric appliances?

Akagi: Initially, I had thought that power electronics is not needed in low-tech products such as electric fans, but the newest fans are being driven by inverters. Ten years ago, vacuum cleaners were still being powered by AC commutator motors, but are now using power electronics. Power electronics is also used in LED lighting.

Eguchi: Power electronics now have a large role in the automobile industry, too. Power electronics is actually being used in a wide range of applications. Please tell us about the basic ways of thinking about power electronics from the perspective of research in consideration of your own research results and rich experience.

Three-Level Inverters and Patents

Akagi: University-level research and corporate-level research and development are slightly different. Research efforts at universities seek novelty and pursue challenges with the expectation that today's high cost technologies will become affordable in the future. Alternatively, when attempting to research subjects that are already in practical usage, professors and graduate students have to find and research something new in analysis, control, design, or other technical aspects.

Eguchi: You have published various types of new theories and technologies such as the instantaneous reactive power theory, or the p-q theory and active filters. You have also researched three-level inverters.

Akagi: During my tenure at Nagaoka University of Technology, I worked in the Power Electronics Laboratory (Power Lab) with Professor Akira Nabae and Associate Professor Isao Takahashi, and we published our results on three-level inverters. Since it was a new university that was established in 1978, there were no graduate students on campus. As a result, I was in charge of the laboratory experiments. It was around November of 1979, I still vividly remember being able to verify our experiment on the adjustable-speed control of an induction motor driven by a three-level inverter.

Eguchi: You never got the three-level inverters patented, didn't you?

Akagi: No, we didn't apply for a patent. At a national convention of the Institute of Electrical Engineers of Japan in March 1980, we published our research paper on the circuit structure of three-level inverters and the adjustable-speed control of an induction motor driven by this new inverter. It is inter-

EGUCHI, Naoya

Born in 1954. Joined Fuji Electric Manufacturing Co., Ltd. in 1980 (now Fuji Electric Co., Ltd.). Fuji Electric Systems Co., Ltd. Board of Directors in 2006. President of Fuji Electric Advanced Technology Co., Ltd. in 2009. Director and Managing Executive Officer of Fuji Electric Systems Co., Ltd. in 2010. Director and Executive Officer of Fuji Electric Co., Ltd. in April 2011, and concurrently serving as General Manager of Corporate R&D Headquarters.

esting to note, but a researcher in the United States was carrying out the same research as ours at the same exact time. This person applied for a patent in Japan. However, since we had published our paper, his patent application was not approved by the Japan Patent Office.

Eguchi: It was fortunate that no patent on the three-level inverter was granted in Japan. After this, the three-level inverter became widely used in industrial fields such as railways and plants. I feel deeply that you are the one who pioneered the development of power electronics in Japan.

Akagi: While I was staying at the University of Wisconsin-Madison as a visiting professor in 1996, I heard from a doctoral student that since the three-level inverter was patented in the United States, it would not be used practically until the patent expired. This resulted in a delay in its adoption.

Eguchi: This is one of the aspects related to patents, and therefore what is a preferable way to obtain a patent is really a sensitive issue.

Akagi: In my opinion, ideas for which a basic patent can be granted should be filed from universities and in other cases, it is best to publish a paper to make the technology public. This is because ideas that can grant a basic patent are not easily generated.

SiC Brings a New Generation to Power Electronics

Eguchi: At first, insulated gate bipolar transistors (IGBTs) as power devices became widespread, and then three-level inverters as circuits. Recently, reverse-blocking (RB)-IGBT power devices have appeared on the market. The technology still doesn't need to take on a new form since there is still plenty of room for evolution based on the fundamentals. You are now also involved in new multi-level converter research, so it seems that you still have a lot of different projects to work on, right?

Recently, Fuji Electric has been focused on development of silicon carbide (SiC) devices. Theoretically, power loss is only one-tenth of silicon devices. We have been making big moves from thyristors to transistors and IGBTs, and now I believe that a new generation is emerging. What are your thoughts on SiC?

Akagi: Our laboratory is actually working on experiments with SiC metal-oxide-semiconductor field-effect transistors (MOSFETs) and SiC Schottky barrier diodes (SBDs), so I know first-hand the advantages of the SiC power devices. The on-resistance of an SiC-MOSFET and the on-voltage of an SiC-SBD are smaller than those of an IGBT, in spite of much better switching characteristics. For example, in a bidirectional isolated DC-DC converter of about 100kW, an IGBT needs to suppress the switching frequency to about 4kHz, but SiC has a low power loss and can be operated at 20kHz, which exceeds the audio frequency. As a result, no acoustic noise is generated.

This can only be due to the fact that it is a different material. When mercury-arc rectifiers were replaced by thyristors, material was changed completely, and I think that the change from Si to SiC is equivalent to that change. The switch from bipolar junction transistors, which were called power transistors in Japan, to IGBTs was a big jump, and I think that the current change to SiC is even bigger.

Eguchi: The research done at Fuji Electric is widely divided into corporate research and business division research. Corporate research is currently dedicating about one-third of its resources to SiC. The Matsumoto Factory has also implemented a manufacturing line that uses SiC six-inch wafers. In addition, it has shifted its operations to support the mass production of SBDs. We are also starting to handle MOSFETs, so I think we can make some considerable achievements within the next two or three years.

Akagi: We had the same experience when power transistors were switched to IGBTs. The first-generation IGBTs that were put into practical use in 1986 were said to have a high on-voltage while also being expensive, but since they possessed good characteristics, a major shift to IGBTs occurred within two or three years. After power electronics engineers recognized their superiority, the trend to adopt them could not be stopped. Then came the 1990s when power transistors were no longer used except for special purposes only. Currently, papers on power conversion circuits using SiC-MOSFETs are steadily starting to appear in academic societies.

Eguchi: Fuji Electric’s development of SiC is based on its joint work with the National Institute of Advanced Industrial Science and Technology (AIST). Joint research with university labs or commissioned research to those was formerly the mainstream as a way of implementing external research and development, but the results never seemed sufficient enough. I thought research didn’t go smoothly unless we worked closely with our counterpart. We are currently sending lots of talented human resources to the AIST. This is open innovation in the true sense of the word. We have been able to achieve our goals and have obtained results that exceed our expectations.

Akagi: I also have been interested in SiC power devices for about 10 years and have been watching closely the papers related to SiC devices and their applications that are published at major technical journals and conferences throughout the world. Honestly, in the beginning, I thought that Japan’s SiC power devices lagged behind those of Europe and the United States. However, it appeared to me that whenever a European or American company produced sample SiC power devices, they easily sold them to users. Japanese companies, on the other hand, were extremely careful in providing users with samples, and therefore I think that this aspect simply cannot be compared to European and American companies.

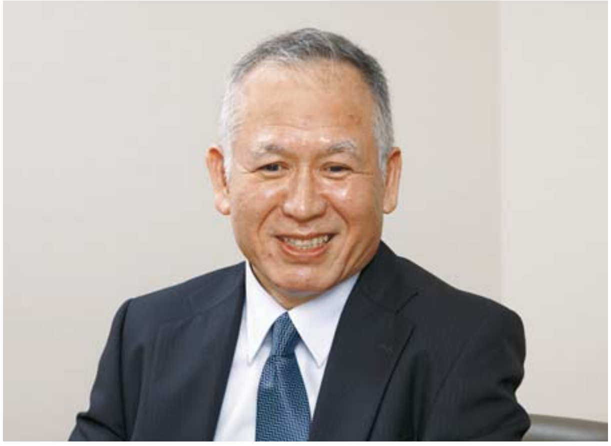
Eguchi: Do you think that Japanese power electronics is leading the way in this field?

Akagi: With regards to large and medium capacity power converters, which are my field of specialty, I believe that Japan has taken the lead. Recently, the focus has been on modular multilevel converters that were originally developed in Europe. The Europeans are extremely specialized in certain areas. Japan focuses on a broader range of research, and from the viewpoint of penetration, I think Japan is not losing.

Eguchi: The development of SiC power devices has expanded the possibilities of power electronics for the future, ranging from a high-frequency field to a high-voltage field. It seems that it will also make a full-scale entry into power systems as well. I believe that the trend is moving closer and closer to your own world of research. Examples of such cases include flexible AC transmission systems (FACTS).

Akagi: Yes, you are right. FACTS were proposed by Dr. Hingorani, the Electric Power Research Institute (EPRI) in the United States in the 1990s. However, at that time, only gate-turn-off (GTO) thyristors were available, so there was a lot of switching loss. Particularly in the case of power system equipment that is always running, it is really important to reduce the loss of power converters. It is equivalent to increasing the fuel efficiency in cars. So, this power-loss problem produced bottlenecks and as a result, FACTS devices and power system equipment that used GTO thyristors didn’t become widespread to a great extent.

When using SiC-MOSFETs in power electronics equipment for power systems, the efficiency is considered to be above 99% in the case of a STATCOM (static synchronous compensator) installed with 6.6kV power distribution lines in Japan. This efficiency is about the same as that of line-frequency (50/60Hz) transformers with the same capacity. Therefore, I think that power loss in converters will no longer be a problem in the future.



AKAGI, Hirofumi

Born in 1951. Assistant and then Associate Professor at Nagaoka University of Technology in 1979 and 1984. Professor at Okayama University in 1991. Professor in the department of electrical and electronic engineering at Tokyo Institute of Technology in 2000 (present post). IEEE Fellow in 1996. IEEE Power Electronics Society President from 2007 to 2008. Scheduled to assume the position of IEEE Division II Director from January 2015 to December 2016. Also active as the IEEE Division II Director-Elect throughout 2014.

Power Electronics is a National Project for Japan and the United States

Eguchi: It seems that we are about to enter a new age where power systems can be controlled by semiconductors. Power devices will also probably evolve more.

At our company, we are currently undertaking research and development of gallium nitride (GaN) as part of wide energy-band-gap devices development, and possibly diamond in the future.

What are your dreams for the future?

Akagi: As I said before, my dream is to reduce the power loss of SiC converters to a level below that of line-frequency transformers of the same capacity. For example, I would like to reduce the power loss of a power converter rated at 6.6kV and 1,000kW, to approximately the same as that of transformers, and in some cases even less. This is a very challenging dream, but I believe it can be achieved through the use of SiC power devices. This is because the performance of SiC power devices will continue to improve in the future.

My other dream is downsizing. Downsized products reduce costs and widen their market. A good example of this is a mobile phone. When mobile phones first appeared on the market, they had to be carried on your shoulders and they were very expensive. However, they became more affordable as their size reduced, and now everyone from a junior high school student to a senior citizen has a mobile phone.

Eguchi: Our dream is to engage ourselves in a rich variety of business projects using power electronics as core technology.

Since wireless communications can now be achieved, the demand for sensors has increased. At the same time, digital signal processors (DSPs) which control devices have achieved higher performance. I believe that intelligent products are feasible through the combination of sensors, control devices and power electronics.

Akagi: That is true. I can give an example of the power conversion based on power electronics. It used to be quite common that a large capacity converter rated at 1,000kW or 10MW consisted of a single conversion circuit utilizing high-voltage large-current power devices. However, now with the ability to exchange information wirelessly with sensors at an acceptable level of reliability allows building up a large capacity converter consisting of serial-parallel connections of multiple standardized medium or small capacity converters with the same voltage and current ratings. Although its control is complicated, we will certainly realize such a converter if the performance further improves in a DSP, which can process digital signals quickly, and in a field-programmable gate array (FPGA), which is an advanced programmable logic device.

Eguchi: With regards to that, I would like to discuss these matters more with professors so that we can further contribute to the future of power electronics.

During a speech on January 15, 2014, President Obama mentioned that Next-Generation Power Electronics Manufacturing Innovation Institute would be established in North Carolina State University, and Prime Minister Abe also spoke about the importance of next-generation power electronics during the 2013 Council for Science and Technology Policy. In both Japan and the United States, power electronics is a keyword of the next generation.

It seems that your role in the future will be increasing more and more. You have also been appointed to an important position within the Institute of Electrical and Electronics Engineers (IEEE).

Akagi: The IEEE is the world's largest technical society with about 400,000 members worldwide. From January 2015, I will assume the position of the Division II Director for a period of two years. This year I was appointed Director-Elect before the official assumption of the position. I will have more opportunities to visit the headquarters of the IEEE in New Brunswick (New Jersey), as well as have more IEEE related work.

Eguchi: Being positioned like that on the international stage will surely help promote the presence of Japan's power electronics.

Akagi: Of course, I intend to do everything I can. Actually, I also have a request. I would like companies to also actively contribute papers to the IEEE.

There are approximately 40 technical societies under IEEE Divisions. Only about 10% of the technical societies are increasing their membership, and the IEEE Power Electronics Society is one of the few societies showing growth in membership. The number of engineers engaged in power electronics in the United States is also increasing.

Pursuing Synergies between Power Electronics and Devices

Eguchi: Power electronics require a wide range of knowledge in many fields, and Fuji Electric has positioned itself in an environment that can pursue synergy effect since it possesses both device technology and application technology. I would like to hear your opinion on this.

Akagi: I think that it is a big advantage to a company when it can do business utilizing both power devices and their applications. Since it is very hard for a single person to fully understand both technologies, I hope that everyone can help each other by asking about certain aspects of the technologies with which he/she is not familiar. I tell the graduate students in the research lab that by self-education, it would take a full two years to completely understand the so-called "vector control," that is a control technology that uses high-performance motor drive systems. However, when I teach them little by little, they continue to steadily make progress in their understanding. I think that if you and other officers take the initiative to break down the barriers between sections in your company, you will create an atmosphere where it is easy to listen to each other freely. This is important because outside of the company, it is very difficult to acquire information.

Eguchi: The power devices section and the power electronics section of our company used to be divided by the force of sectionalism, but there are no longer any more barriers between these two sections. I inherited the duties of the Technological Development Department at Fuji Electric from Dr. Shigekane, who specialized in devices. Since I was specializing in circuit applications, we both led engineers so that barriers would not be built. Also, when we were developing a new power device for three-level inverters, we decided the specifications based on the requirements of the circuit, and in the development of a SiC power device, device and circuit engineers discussed how to make full use of the technology.

Efforts to Develop a Smart Grid

Eguchi: Recently smart communities and smart grids are attracting a lot of attention, and I think this is probably a market in which power electronics can be used effectively. Please tell me what your outlook is on this market.

Akagi: Smart grids, defined in a broad sense, are to solve an issue of voltage and frequency stabilization if a large amount of fluctuating or intermitted electric power such as solar and wind power flows into utility transmission and distribution systems. Therefore, the amount of electric energy to be used needs to be adjusted to a certain extent on the utility customer side. Dynamic pricing intended for changing the charge of electricity, depending on the time period, has also been undergoing demonstrating projects in Japan. On the other hand, the development of grid-level battery energy storage systems that store and release electric energy is also urgently being pursued. Since roof-top photovoltaic power generation (PV) systems for individual houses, office buildings, and factories have come down in price, I expect that they will be widely used.

Eguchi: If that is the case, a micro grid will be an important factor, and also it will be extremely important to determine how to efficiently use the direct current (DC). I think that the unidirectional or bidirectional isolated DC-DC converter technology that you are working on will become increasingly necessary.

Akagi: Yes, I agree. There are two reasons why Edison’s DC distribution lost out to the AC distribution developed by Tesla. One reason is that the electrical engineering technology at the time had hardly to freely change DC voltage. The other reason is related to a DC circuit breaker for protecting the DC system against a large amount of DC fault current. The leading-edge power electronic technology can solve the two problems inherent in the DC distribution. Of course, to change DC voltage, DC power is being converted to high-frequency AC power, but bidirectional isolated DC-DC converters have also become a sufficient target for utilization. I believe that DC power transmission and distribution systems will become widespread in a wide range of applications, which include its usage in the home.

Even though GTO thyristors weren’t able to achieve practical usage due to cost and performance issues, the development of SiC-MOSFETs has opened the door to a whole new direction.

Power Electronics Requires Extensive Knowledge

Eguchi: Our biggest concern now is that there are not enough power electronics engineers. Do you have any good advice with regards to this problem?

Akagi: Since power electronics requires a vast range of knowledge, it obviously takes a very long time to train people in this field. As a result, universities are often not able to provide companies with the human resources they demand.

Power electronics requires a basic knowledge of circuits as well as an understanding of control technology. On top of this, engineers are also required to know analog and digital signal processing based on the latest A/D converters, DSPs, FPGAs and so on. When doing research and development on adjustable-speed motor drives, it is obvious that knowledge of motors is essential. In the case of the power electronics equipment being installed on power systems, knowledge is required of the power systems. And then, an understanding of semiconductors is needed to master the usage of power devices. This results in being related to almost all the courses in electrical and electronic engineering departments. Engineers who graduated with degrees in fields other than electrical and electronic engineering will need to first study circuit theory and electromagnetics, and after this they will have to proceed into the study of power electronics circuits.

Another problem is that there are not enough instructors who can guide students along the path of researching power electronics. Even at a hub university, there is only one power electronics laboratory. The reason why there are so few qualified instructors is because of the high amount of emphasis placed on research results and papers when hiring university faculty members. Power electronics research papers require a lot of time to write since they include nearly all of the content required in engineering papers such as research theme setting, analysis, simulation, laboratory experimental design and set-up, experimental data evaluation, and so on. The result is that the number of research papers written by instructors in this field is far less than that in other fields. In the field of electrical and electronic engineering, the goal is not to hire a wide diversity of instructors, but there needs to be means for evaluating instructors limited to those who specialize in power electronics, or by emphasizing the qual-

ity and content of research papers rather than the quantity of them.

Eguchi: Since students who are trained well by the qualified university instructors will immediately contribute to the workplace, it is my hope that we will be able to employ some talented young people.

Fuji Electric is currently doing power electronics R&D overseas in countries including Germany and the United States, but it is very hard employing overseas personnel. From your perspective, what do you think are the differences between researchers in Japan and overseas researchers?

Akagi: Internationalism is the big difference when compared to the United States. Many of the students studying power electronics in the U.S. were not born and raised there. Many come from India and China. Most of the directors of the IEEE Power Electronics Society were also not born and raised in the U.S. Out of approximately thirty members, only about three of them were raised in the United States. American society readily accepts people who have specialized abilities. From a different perspective, people who speak English as their native language also have a big advantage.

However, when thinking about this issue from different angles, I don't think it is appropriate to compare Japan and the U.S. I have always thought that it is better to compare Japan and Germany since Germany is characteristically similar to Japan in many aspects. The U.S. is totally different when it comes to geographical size, natural resources and the cost of energy such as electricity. It is also different with respect to its perspective on research.

How to Increase the Number of Power Electronics Engineers

Eguchi: Fuji Electric is now trying different strategies to train and cultivate their young employees to prepare them for work in next-generation power electronics. Tsukuba University has established an endowed course on power electronics, and I will work as an instructor for the power electronics summer school held every August at Tsukuba Innovation Arena (TIA).

Akagi: I have also been giving lectures since 2012. There have also been some famous lectures by Dr. Shigekane of Fuji Electric. The vice president himself gave a 90-minutes lecture that really inspired young students and engineers. So, from this year, the baton has been handed over to you.

Although students receive four days of lectures during summer school, what they learn is usually not immediately apparent to them, but it gives them some valuable hints and tips that they will find very useful later on in their lives.

The graduate students attending these lectures are the people who will be engaged in the future work of power electronics at universities and companies. Of course, some engineers who are actively working at companies also attend the lectures, and it is a lot of fun giving the lectures. You'll see the sparkle in the eyes of the students. I have also been teaching power electronics to students in the second half of their third year as part of the electrical and electronic engineering curriculum at my university. Although about 60 undergraduate students attend my lectures, I would say that only about 10% of them will work in the field of power electronics in the future.

Eguchi: I think that the challenges provided by the summer school will be a good chance to cultivate Japan's engineers so that they can contribute to the development of power electronics.

Akagi: What is difficult about power electronics is that even though they are used in our most familiar equipment and appliances such as Shinkansen bullet trains, refrigerators and air-conditioners, they exist in their sub-systems, so power electronics remains hidden to most people. Most people seem really interested in technologies such as the motor drive system (sub-system), which is one of the core technologies of the Shinkansen system. Therefore, I would like to see the mass media write more articles that focus on the sub-systems of these systems.

Eguchi: By appealing the technology to the general public, don't you think that the number of students studying power electronics will increase in the future? I would also love to see women become interested in this field.

Akagi: It is sad to say, but the number of women interested in power electronics in Japan is very small. I have given a lecture of power electronics for nearly 13 years at the Tokyo Institute of Technology, and there have never been more than 3 female students in class, and in some years there were none. In the U.S., there are always a certain number of female students in class whether it is at Massachusetts Institute of Technology (MIT) or at the University of Wisconsin-Madison.

Eguchi: There are four women engineers working in the power electronics development center at Fuji Electric. I think that if we can find a way to get women more involved, we will also be able to increase the number of power electronics engineers.

Akagi: In Japan, there are about 15 universities that provide a complete education in power electronics from theory to lab work. When it is assumed that about 6 students finish their master's degree programs at each school every year, these 15 universities produce about 90 engineers in total, and many companies in need of engineers scramble for these 90 very valuable students.

On the other hand, from the perspective of the students, they never need to worry about finding jobs. The master's degree students in my laboratory are very popular with recruiters. Doctoral students are also actively employed at many companies. Although the mass media runs with stories that say things like "Even People with PhDs Cannot Find Work," this certainly is not the case for students studying power electronics.

Encouraging Japanese Engineers to Become More Active Internationally!

Eguchi: Fuji Electric intends to expand its business more internationally, but it is still not completely possible to hire power electronics students from overseas institutions. Since language problems would be a big obstacle, we have been hesitant to hire people from abroad.

Akagi: Setting aside conversation in Japanese, reading and writing Japanese are difficult to engineers from abroad. Furthermore, it is not always possible or practical to translate information into English. For Japanese engineers, it's better to master English. Their first goal is to learn their specialized technology well, and English is usually a secondary goal to them.

According to one Japanese engineer that I know, when he was younger, he was able to speak broken English and somehow managed to use this skill to do his job. Thinking about this, I would say that since he knew the technology, his colleagues would carefully listen to him, regardless of how bad his English was. On the other hand, if he didn't know the technology, they probably wouldn't have listened to him no matter how good his English was.

Eguchi: That seems to be the nature of things. There are currently six engineers of Fuji Electric studying abroad. They are taking courses at RWTH Aachen University in Germany and the University of Wisconsin-Madison in the United States. They all specialize in devices, but they are studying circuits to expand their potential. We also have a software specialist who is attending Swiss Federal Institute of Technology (ETH). He is studying power electronics device design. We are sending our employees to various countries so that we can also gain a more global perspective and advantage.

Akagi: If they can spend a year or two in the laboratory, they will make a great network of human connections, and Fuji Electric can definitely make use of this in the form of exchange and discussion opportunities. Studying abroad is extremely important in this sense.

Personally, I have visited many countries around the world on business. If I count them all, I would say that I stayed at least one night in 36 different countries. When you go abroad, you get the chance to meet various engineers of different religions and races, but when you talk one-on-one about technology, it is basically the same as talking to a Japanese person. It is within the range of different personalities.

I would really like to see Japanese researchers and engineers become more active overseas by pursing activities such as publishing papers at the top class international conferences in Europe and the United States.

Eguchi: We here at Fuji Electric have high aspirations as we develop power electronics as our core technology to contribute to people all over the world from the perspective of energy and the environment in areas such as energy savings, the promotion of renewable energy and the reduction of CO_2. We have an urgent need to train engineers who can be active on the international scene as we grow our business globally. Professor Akagi's support is greatly needed and appreciated by us here at Fuji Electric, as well as by the young engineers of the world who carry the future of power electronics on their shoulders. I thank you very much for visiting with us today.

Fuji Electric
Innovating Energy Technology