by Hirofumi Akagi and Fang Z. Peng

Reminiscing Prof. Akira Nabae's Successful Voyage From the Mercury Era to the Silicon Age

Dr. Akira Nabae, Professor Emeritus of the Nagaoka University of Technology, Nagaoka, Japan, died of old age on the morning of 25 January, 2021 with his wife, Michi, and his daughter, Saori, by his side at home. He was 96 years old (Figure 1). The power electronics community has lost a giant in the field of power conversion systems and motor drives. Prof. Nabae was well-known as a pioneer of vector control or indirect field-oriented control of induction motors, and as an inventor of the three-level neutral-point-clamped (NPC) inverter. The monumental paper entitled "A New Neutral-Point-Clamped PWM Inverter" was published in the IEEE Transactions on Industry Applications in 1981. According to *Google Scholar*, this original paper has been cited more than 6000 times, and is still counting. Since March 1999, the Japanese high-speed bullet train, the Shinkansen, has been using the three-level NPC inverter for driving the main traction induction motors. Prof. Nabae made "a successful voyage from the mercury world to the silicon compound planet," by successfully transforming power conversion technology from the mercury era to today's silicon age.

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FIG 1 Prof. Akira Nabae, 1924—2021.

Prof. Nabae was born in Ehime, the northwest of the Shikoku island, Japan, in 1924. He received the B. E. degree in electrical engineering from the University of Tokyo, Tokyo, Japan, in 1947, and the Dr. Eng. degree from Waseda University, Tokyo, Japan, in 1978.

After joining Toshiba Corporation, Japan, in 1951, he started his legacy career with research and development on mercury-arc rectifiers at the Tsurumi Works, Yokohama, Japan, from 1951 to 1965. One of his technical contributions was to make experimentally clear a relation between physical phenomena inside a mercury-arc rectifier and electrical properties determined by the external circuit. This work contributed to dramatically suppressing a probability of arc-back. For years, mercury-arc rectifiers were being used for general rectifiers, dc motor drives for paper and steel mills, metal refining, ac electric locomotives, dc railway substations, frequency changers between 50 Hz and 60 Hz power systems, and so on.

When the silicon-controlled rectifier (SCR), or referred to as the thyristor later, was invented at GE in 1957, a new silicon-based power conversion technology had emerged. As silicon-controlled rectifiers increased in voltage rating and current rating, they gradually replaced mercury-arc rectifiers because they were much more compact in size, much lighter in weight, and much lower in forward voltage drop than mercury-arc rectifiers. He was the last general manager in the division of mercury-arc rectifiers, not only at Toshiba but also among Toshiba's competitors around the world.

After the mercury-arc-rectifiers division was shut down completely, many of his team members moved to Toshiba's Hama-Kawasaki Works, Kawasaki, Japan, in 1965. He led his new team to research and development on vacuum circuit breakers on the basis of vacuum mercury-arc rectifiers. Then, he moved to Toshiba's Heavy Apparatus Engineering Laboratory, Fuchu, Tokyo, in 1970. He, as a chief research scientist, conducted research and development on

FIG 2 Prof. Akira Nabae (front center) enjoying sake with his research group in Nagaoka in 1986.

power electronics and motor drives. His team succeeded in developing the 55-kW (30-min power rating) water-cooled inverter using 12 newly-developed bipolar junction transistors rated at 1000 V and 200 A, intended for a pure electric vehicle (EV). This was a pioneering contribution looking forward to the market of today's EVs. This success became his motive force of conducting research on vector control of induction motors.

In April 1978, he was appointed as an inaugural Professor in the Department of Electrical Engineering at the Nagaoka University of Technology, Nagaoka, Japan. This university was established in October 1976, which was characterized by emphasizing graduate-student education and industry-university collaborative research. He established and led a new power electronics research lab, including hiring us as a junior professor and his first Ph. D. students, respectively in 1979 and 1984. This lab had become one of the world's renowned power electronics research group in the 1980s. In 1986, Prof. Nabae was invited to China to establish the Power Electronics Society, serving as an adviser and a keynote speaker at its very first power electronics conference. In 1990, he retired from the Nagaoka University of Technology and moved to the Tokyo Institute of Polytechnics, Atsugi, Japan, as a Professor in the Department of Electronic Engineering until his retirement in 1997. He was an open-minded professor, and loved Japanese "sake" or Japanese rice wine because Nagaoka is famous as the center of the best sake brewers in Japan (Figure 2).

He received many prestigious awards and recognitions from the IEEE and the Institute of Electrical Engineers of Japan (IEEJ), including the 1984 IEEJ Transactions First Prize Paper Award, the 1990 IEEE Fellow Grade, the 1991 IEEE Transactions on Industry Applications First Prize Paper Award, the 1993 IEEJ Outstanding Achievement Award, the 1996 IEEE Power Electronics Society William E. Newell Award, and the 1999 IEEE Industry Applications Society Outstanding Achievement Award.

Prof. Nabae was our mentor and role model, and he has left a great mark on us and many others. While he had many significant technical accomplishments during his industrial and academic career that spanned many decades, his enduring legacy will be in those people that he mentored, collaborated with, and instilled a research and entrepreneurial spirit that will continue.

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