The Achievements of Yokogawa’s Measuring Instruments over the Past 100 Years and Our Commitment to the Future

Kenichiro Haga *1

Yokogawa Electric Corporation was founded in 1915 to manufacture analog meters. Since then, Yokogawa has been leading the measurements industry in Japan, especially in the areas of power and waveform measurement, and this year we celebrate our 100th anniversary. This paper reviews some of the 100-year achievements of Yokogawa’s measuring instruments in the area of electrical energy, which is regarded as important for achieving a global mission of sustainable societies. This paper also covers today’s measurement targets, the relevant technological issues, and the trends of international standards towards enhancing more efficient energy usage.

INTRODUCTION

Yokogawa was founded in 1915 and became the first company in Japan to manufacture electrical measuring instruments. The company’s first challenge was to develop analog meters, indicating meters that can measure voltage, current, and electric power. The next challenge was to commercialize electromagnetic oscillographs that could visualize the behavior of electrical signals. Now, in 2015, just 100 years after its founding, Yokogawa’s measuring instrument business is aiming to position electrical energy as its main business domain. In this area, the major measurement targets are electric power and waveforms. The technologies and concepts of Yokogawa’s existing products have been inherited from those that were created in the company’s early days. Although the shapes of products have changed in line with the progress and evolution of various technologies, at a fundamental level, our goal of optimizing measuring of the same electric parameters as those that were measured in the days of analog meters is still important and essential.

It is well known that electricity is obtained from the product of current and voltage. However, to obtain correct values, it is necessary to precisely measure both voltage and current. Meanwhile, various attempts have been made to visualize the dynamic behavior of normally invisible electric signals. Observation of the dynamic behavior of a signal is crucial, especially when the control over the behavior is required. Waveform measurement technology has progressed as a result of this requirement. The first part of this paper reviews Yokogawa’s 100-year history of measuring electricity and waveforms, both of which are the fundamental targets of measuring electricity. This paper then presents a summary of the evolution of switching devices, which play the lead role in the modern field of electrical energy, and issues related to measuring them. Finally, this paper discusses activities aimed at creating a sustainable society.

HISTORY OF POWER MEASUREMENT TECHNOLOGY: EVOLUTION AND CHALLENGES

In 1917, two years after its foundation, Yokogawa released Japan’s first indicating meters: ammeters, voltmeters, and power meters. Then, Yokogawa developed the Y-20 integrating wattmeter, shown in Figure 1, which was officially approved by the then Ministry of Posts and Telecommunications later on.

Figure 1 SPB model portable AC ammeter and Y-20 model integrating wattmeter for single-phase AC (released several years after Yokogawa’s foundation)

*1 Strategic Development & Engineering Department, Yokogawa Meters & Instruments Corporation
In those days, electric power was mainly used for lighting, however, it gradually came to be used as a power source. Because this shift led to a significant increase in power consumption, the electricity rate system was changed from a flat rate to a metered rate system. This meant that households and companies were billed according to the amount of electricity they consumed. Billing according to consumption led to a drive toward achieving greater accuracy in measuring power.

The accuracy requirement in those days to integrate wattmeters mounted on distribution boards, which require durability, was about 5%, while the accuracy requirement in terms of the standard used for calibrating meters mounted on such boards and ordinary meters was 0.1% to 0.2%. Engineers are typically forced to ensure quality and accuracy. A power meter in those days was of the electrodynamometer type. This was a precision instrument that used electromagnetic power, which consisted of a fixed coil and a moving coil rotating inside a fixed coil, and operated according to the principle that the generated driving torque is proportional to the product of the currents of the two coils.

In the second half of the 1950s, soon after World War II, Japan enjoyed an unprecedented economic boom in which electrical home appliances became common features in every home. In those days, the three main products everybody wanted were black-and-white TV sets, washing machines, and refrigerators. On the industry side, the shift of power sources to electric power progressed rapidly and the era of mass electricity consumption began. As a result, demand increased for high-precision power measuring of harmonic components of kHz orders, although the frequency requirement for measuring power only covered commercial frequencies of 50/60 Hz so far. To satisfy this need, Yokogawa developed high-precision power measurement technology and produced the first power converter device, the APR, in 1960. This was an automatically balancing-type power converter based on an electrodynamometer, which detects the rotary power generated by electric power to be measured, and generates opposing rotary power to balance it. It converts opposing rotary power, i.e. feedback current to the measurement system, into voltage, and outputs it as electric power. This was a highly accurate power converter that had error of less than 0.03% in DC to 500 Hz, and less than 0.1% even at 1 kHz. The improved APR-2 model was highly evaluated by the National Bureau of Standards (NBS) as a standard power meter and received official approval in the U.S. and Canada. This helped Yokogawa’s high quality technology become known globally. Figure 2 shows its external view and measurement principle (1), (2).

![Figure 2-a External view of the APR-2 standard power meter](image_url)

**Figure 2-b Measuring principle of the APR-2**

In the 1960s, power measurement technology began to shift from electric to electronic. In order to precisely calculate the product of voltage and current, a highly precise multiplier using a time-division multiplication method was devised. This principle is shown in Figure 3 (2). Rectangular waveforms at a constant interval with the pulse width and proportional

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Note 1) The unit for frequency and spatial frequency was cycle, for example, represented as "c" or "c/s," which was permitted for use by the Measurement Law of Japan until September 30, 1995. At present, hertz (Hz), as defined in the International System of Units, is used.
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HISTORY OF PROGRESS IN WAVEFORM MEASUREMENT TECHNOLOGY AND RELATED CHALLENGES

Waveform measuring from an electric viewpoint involves visualizing and recording changes in voltage and current that are normally invisible. Yokogawa’s first products were analog meters as mentioned above. However, according to Yokogawa’s 50-anniversary commemorative publication (3), the product that realized stable company management after the company’s foundation was the portable electromagnetic oscillograph. Inside the oscillograph, a reflecting mirror is fixed to the shaft of a moving-coil type galvanometer with a high natural frequency, which is called an oscillator, and a light beam is irradiated toward the mirror. When current is applied to the galvanometer, the shaft rotates proportionally to the applied current, which triggers corresponding changes in the direction of reflected light. The reflected light is recorded photographically over time, which helps visualize the changes in current. In those days, imported electromagnetic oscillographs were very expensive. In 1924, Yokogawa successfully manufactured an electromagnetic oscillograph shown in Figure 4 for approximately half the cost of imported versions. The release and spread of this oscillograph enhanced the reputation of Yokogawa’s technology and triggered the development of more precise products. With continuous improvement, electromagnetic oscillographs remained the major source of Yokogawa’s revenue for a long period of time until cathode ray tube (CRT)-type oscilloscopes became popular after World War II.

Yokogawa also developed CRT-type oscilloscopes. The OL-51B oscilloscope shown on the left of Figure 5 was featured in the lead article in the first issue of Yokogawa Technical Report in 1957 (4). Advances in electronic and semiconductor technologies in the late 1980s promoted rapid digitization of measuring instruments. New CRT oscilloscopes were put on the market equipped with several kilobytes of waveform memory. Yokogawa released its first digital oscilloscopes in 1988. The DL series, including the DL2100, DL3100, and DL1200 shown on the right of Figure 5, featured full digital processing after A/D conversion of input signals, based on the technology and knowledge that was amassed during the development of products such as the 3655 analyzing recorder.
The DL series oscilloscope was an epoch-making product particularly in the area of practical usability, and featured a memory capacity of up to 512 kB per channel, quick response, a built-in printer, and a large range of waveform calculation functions. This DL series pushed our competitors to follow Yokogawa’s lead by equipping their digital oscilloscopes with large capacity memories and enhancing their products’ analysis functions. With the same sample rate, the larger capacity memory facilitates longer measuring times, and with the same measurement time interval, it enables measuring with higher time resolution. This product has become popular particularly within the field of mechatronics, electrical drives, and lighting where there is strong demand for the ability to observe transient responses in detail.

The functions and performance of this series have progressed significantly and have been inherited in the DLM2000 and DLM4000 series oscilloscopes shown on the left of Figure 6. These are equipped with advanced functions for analyzing waveforms, electric power, serial buses and other items. The DL850E series scope coder shown on the right of Figure 6 is also on the market. This device can measure various measurement parameters in multiple channels simultaneously by using various modules. Importantly, all products follow the basic concept of realizing practical usage.

Figure 5 OL-51B oscilloscope (left) and DL1200 oscilloscope (right)

TODAY’S TECHNOLOGY FOR CONVERTING ELECTRICAL ENERGY AND ISSUES RELATED TO MEASUREMENT TECHNOLOGY

This paper has presented a review of Yokogawa’s history in the area of power and waveform measuring to date, both processes of which play leading roles in the area of electrical
energy measuring. This chapter examines measuring-related requirements in the electrical energy market, which Yokogawa's measuring instrument business is focusing on.

Evolution of Power Devices and Front-end Technologies for Their Measurement

Progress in electrical energy application technologies in recent years has been supported by the evolution of semiconductor power devices and control technology. As shown in Figure 7, the transistor was invented in the 1940s, followed by the thyristor in the 1950s. In the 1960s, mercury rectifiers were replaced by thyristors. As a result of a drive to realize greater power and efficiency, the power MOSFET was put into practical use in the late 1980s, followed by the insulated gate bipolar transistor (IGBT) in the 1990s. Both these devices are the main components used in inverters today. The shift of the material used for a switching device to silicon carbide (SiC), which is a next-generation material, began in the 2000s. The development of power devices using gallium nitride (GaN) is also underway. In addition, control technology is also evolving from analog to digital, enabling precise control responding to specific loads and situations.

When observing this evolution from the viewpoint of measuring instruments, these instruments need to measure high voltage and large current signals, and rapid changes in both. For the purpose of ensuring highly accurate and stable measuring, the role of measurement technology such as probes, sensors and front-end technology for high noise resistance is becoming more important than ever.

Integration of Power Measurement and Waveform Measurement

As mentioned above, power measuring instruments and waveform measuring instruments have evolved independently; the former evolved due to a requirement for higher accuracy, and the latter due to a requirement for multi-channel waveform observation and analysis. However, now, there is an increasing need to measure the dynamic behavior of power consumption precisely and in detail depending on the progress of electronic devices and the advances made in control technology for inverters. The PX8000 precision power scope, released in 2013 and shown in Figure 8, was developed on the basis of the wide-band, high-precision waveform measuring instrument with a sampling rate of 100 MS/s and a bandwidth of 20 MHz. This is a unique measuring instrument that can perform power calculations with guaranteed high level accuracy in the specified interval of voltage and current waveforms. This function is useful for measuring loss during the transient state at the start-up of electronic devices or when optimizing switching waveforms. The PX8000 satisfies customer requirements by combining existing technologies for measuring power and waveforms. There now seems to be more possibilities to enable measuring of phenomena that were not able to be measured before by not only pursuing performance of individual technologies but also combining different technologies and/or products.
electricity, the energy utilization efficiency of electronic devices has been markedly improving. However, the increase in total energy consumption has outpaced it. As a measure carried out within the industry to overcome this situation, the International Organization for Standardization (ISO) established the ISO50001 international standard for energy management systems\(^{(5)}\) in June 2011. This standard defines the energy management processes required for each organization to achieve continuous improvement in energy efficiency. However, only achieving results is not sufficient; companies and other organizations are also required to build and operate an optimum management system as shown in Figure 10.

Against such a situation where regulation of energy consumption is becoming increasingly strict, the industry must improve efficiency in supply, transportation, and consumption of energy through technological innovation in order to minimize negative influences on economic activities caused by the regulations. Because dependency, particularly on electrical energy, of the industry has been increasing in recent years, not only is it necessary for measuring instrument manufacturers to ensure instruments measure accurately, it is also necessary for them to create solutions in which efficiency improvements and conformance evaluations contribute to society.

**CONCLUSION**

This paper introduced the 100-year history of Yokogawa’s efforts activities to measure electricity. We hope this has helped you gain a greater understanding of how Yokogawa has improved its technologies in response to the changing needs of society, and contributed to society as a whole. This paper will conclude with words from Yokogawa’s 50-year anniversary publication: “Human beings progress with measurement. Measuring instruments improve as long as human beings progress.”

**REFERENCES**

(3) Edited by Yokogawa Electric Works, Yokogawa’s 50 years: Pursuing Measuring Instruments, Yokogawa Electric Works, 1965 in Japanese

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