

Present Status and Prospects of High-Power Conversion Systems

Ginjiro Yanai

1. Introduction

General industry, electric utilities and electric railways consume or transmit large amounts of electric energy. In these fields, electric energy is chiefly utilized for heating, chemical reactions and motive power. For those purposes, large-capacity power electronics equipment is installed at intermediate locations to meet respective requirements and to effectively utilize electric energy.

In the past, these fields have required averagely controlled electric power. Nowadays, however, the quality of electric power has also to be considered from the viewpoint of whether it enhances product quality, speeds up production, and is suitable for improving the environment we live in, such as by stabilizing system voltage and incinerating waste disposal. As a result, it is required of power supplies that voltage, current and frequency are not only averagely controlled, but that the voltage and current waveforms can be instantaneously controlled and generated freely according to load requirements. For that purpose, the configuration of power supply systems and the performance of power semiconductors, particularly switching speed, must be improved.

Power semiconductors used in power electronics devices have been improved substantially and large-capacity, high-speed power semiconductors have been developed and commercialized one after another. High-speed processing by controllers has been made possible due to the progress of microprocessors. The functionality of power electronic devices has remarkably been enhanced, allowing power supplies to meet market demands.

This paper describes the present status and prospects of power supplies in the fields of general industry, electric utilities and electric railways.

2. Power Supply Equipment for General Industries and Electric Utilities

Figure 1 shows the relationship between the types and applications of large-capacity power supplies for industrial use. Industrial applications can roughly be

classified into the categories of heating and melting, metal surface treatment, welding and cutting, radiation-applied chemistry, voltage stabilization, electrolysis and other special applications. Each application requires a power supply suitable for that particular application. Requirements of power supplies are no power interruption and good quality, low equipment cost, and high adaptability to the application. Therefore, manufacturers of power supply equipment are concentrating their energies on improving power semiconductors, making smaller size and space saving power units and systems, and enhancing reliability and efficiency through the adoption of proper system configurations and components.

This paper describes power supplies for electrolysis, metal surface treatment, heating and melting, and voltage stabilization, but does not include descriptions of power supplies for motor applications such as variable speed drive and UPS (uninterruptible power supplies).

2.1 Electrolysis

Electrolysis used for aluminum reduction, chlor-alkali and other material production requires an extremely large amount of DC current from a DC power supply. The power supply voltage is 1,500 V or less.

The voltage and current of aluminum reduction furnaces have been increased in order to reduce cost. The largest capacity reduction furnace currently in operation is 400 MW. Construction of a 550 MW (1,550 V, 350 kA DC) furnace is planned, and in the future much larger capacity furnaces may be realized. Figure 2 shows the transition of the rated voltage and current of aluminum reduction furnaces. As can be inferred from the figure, technology for large-capacity power supplies plays an important role in the field of reduction furnaces. For details, refer to another paper, "Transformer-Rectifier Package (S-Former) for Aluminium Smelting," in this special issue.

There are several types of cells for chlor-alkali. These days, bi-polar cells are used in most cases due to their high production efficiency. A bi-polar cell has multiple cells, for which three types of power supply

Fig.1 Applications of large-capacity power supplies

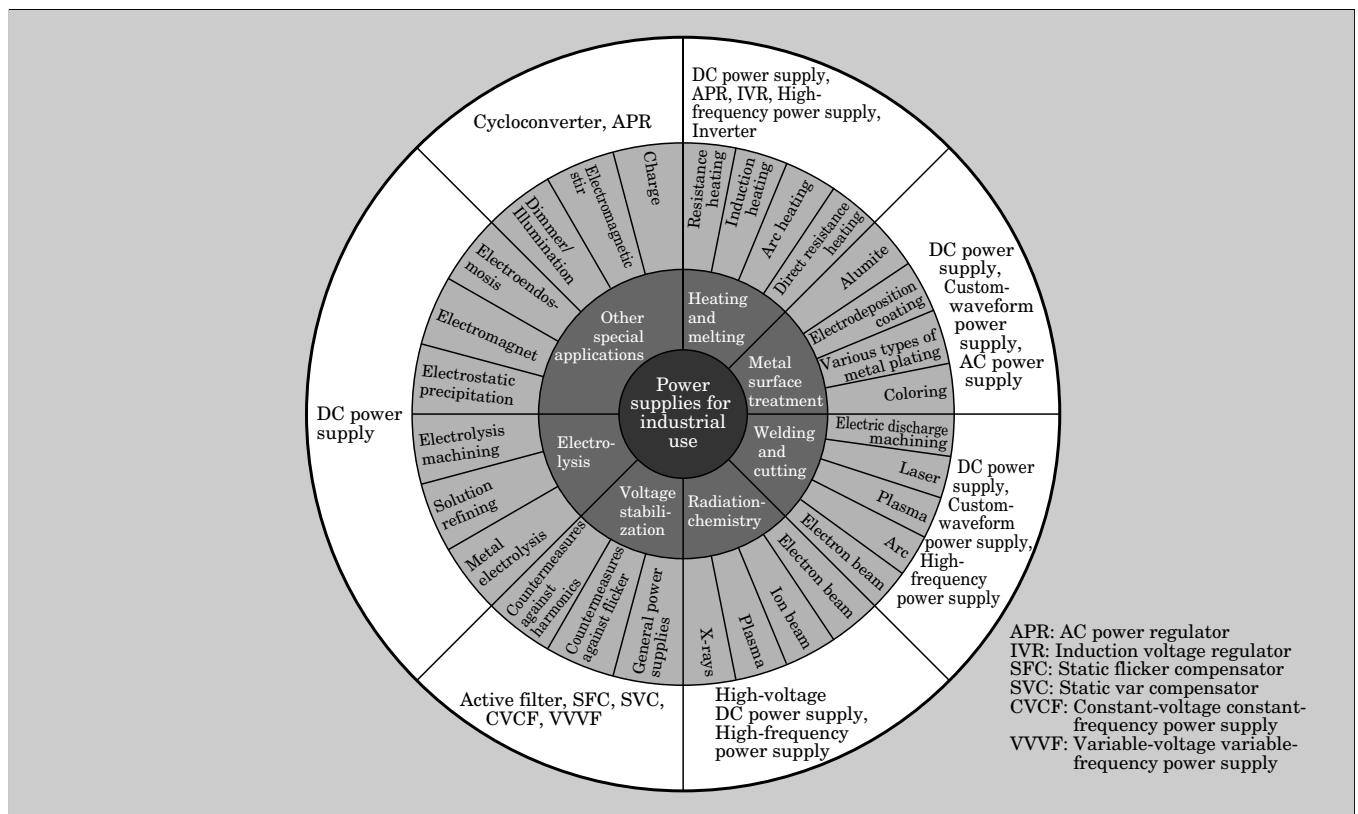
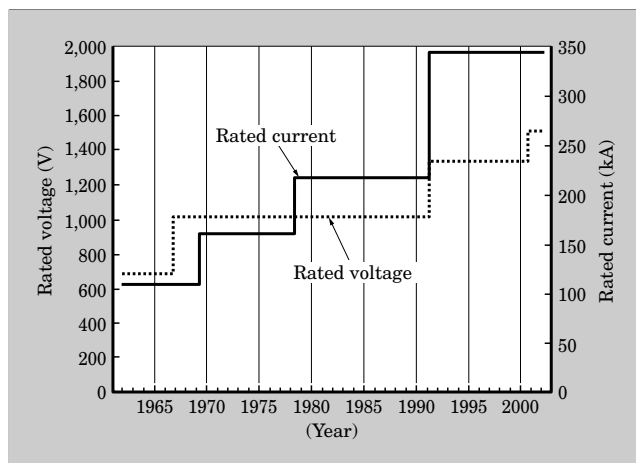


Fig.2 Transition of the rated voltage and current of aluminum reduction furnaces



system configurations are available as shown in Fig. 3. The most suitable power supply system configuration is chosen from among these three kinds, based on considerations of equipment cost, installation space and reliability. The system configuration used most commonly these days is type (b), because of its excellent characteristics with regard to cost and space. Type (c) has the advantage of a higher power factor and lower harmonics, and will be preferable to the two other types if large-capacity self-commutated semiconductors are developed. The development of large-capacity self-commutated semiconductors and their

application technology will be necessary in the future.

2.2 Metal surface treatment

Plating and coloring are typical metal surface treatments. The rather small power supply capacity for these treatments is 1,000 kW or less. To improve quality and productivity in metal surface treatment, each metal surface treatment company possesses their own proprietary processing solution and expertise in applying special voltage and current waveforms. Typical examples of metal surface treatments are as follows.

(1) Coloring of aluminum sashes

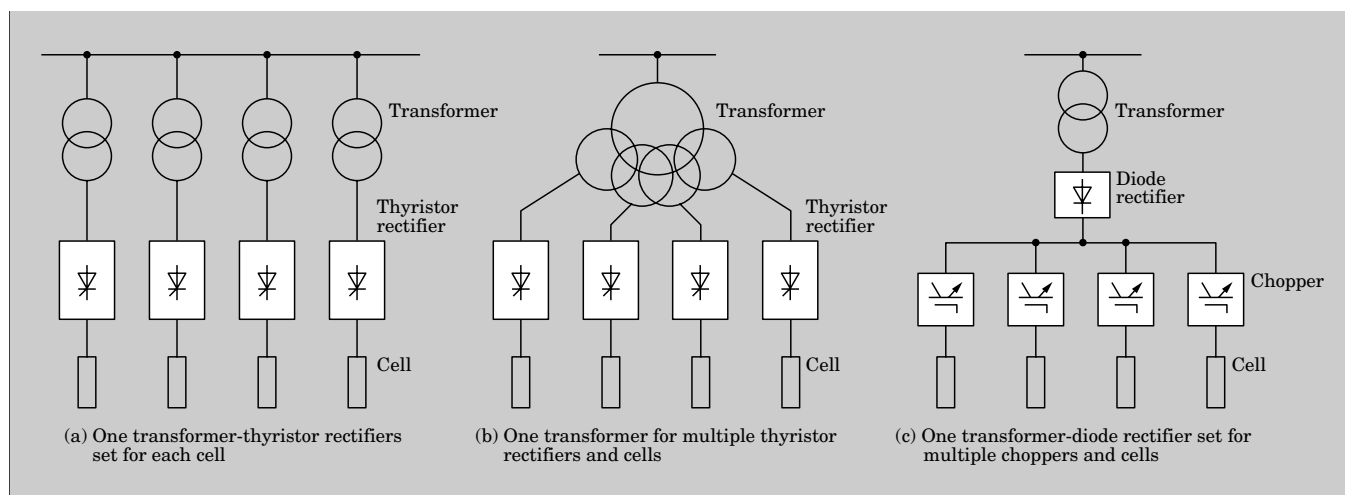
Coloring with uniform quality can be performed on an aluminum sash regardless of its size and its position in the cell, leading to an excellent yield rate.

(2) Plating of printed circuit boards

Through-holes can be plated in the same quality as the surface of a printed circuit board.

Large-capacity power supplies with special voltage and current waveforms are required in these fields. Programmable power supplies that utilize large-capacity inverter technology can be applied. Recent large-capacity, self-commutated, high-speed semiconductors enable the manufacture of 150 V, 10 kA-class programmable power supplies. A certain surface treatment company has introduced this power supply into an aluminum coloring process and has achieved excellent performance results. For details, refer to another paper, "Custom-Waveform Power Supply for Metal

Fig.3 Power system configuration for chlor-alkali



Surface Treatment,” in this special issue.

2.3 Heating and melting

Heating and melting applications are found in a wide variety of processing fields. This paper describes the melting of ash from urban waste incinerators, which is attracting attention from the viewpoint of environmental preservation.

The disposal of municipal waste in Japan is increasing year after year, and in 1997 reached 51.2 million tons annually, and incinerated ash exceeded 6 million tons. Owing to a shortage of landfill sites for incinerated ash, recycling systems to melt and solidify the ash, and then to utilize the solidified product as construction material (gravel) are recently attracting a great deal of attention.

There are two types of these recycling systems, electric and combustion types. An electric-type system facilitates easy separation of heavy metals, and is environmentally friendly.

Arc furnace systems are currently widely used in electric-type recycling systems and have a power supply capacity of 70 to 100 kW/t. The rated voltage of the power supply for the arc furnace is set to a voltage higher than the normal operating voltage in order to prevent the arc from being extinguished. Its power supply circuitry is not composed of thyristor, but of 10 kA-class high current choppers, because thyristor rectifier would substantially reduce the power factor.

2.4 Voltage stabilization

The recent progress of semiconductors has enabled their use in various applications to improve production operations and to make daily life more convenient. On the other hand, semiconductors introduce various disturbances into the power supply networks, such as light flickering, make the system more susceptible to unstable system voltage and power supply equipment breakdown, and reduce the utilization factor. The use of var compensators resolves these issues and stabilizes

es system voltage. Var compensators mainly consist of the following three types:

- (1) Thyristor-controlled reactor (TCR)
- (2) Self-commutated static var compensator (STATCOM)
- (3) Thyristor-switched capacitor (TSC)

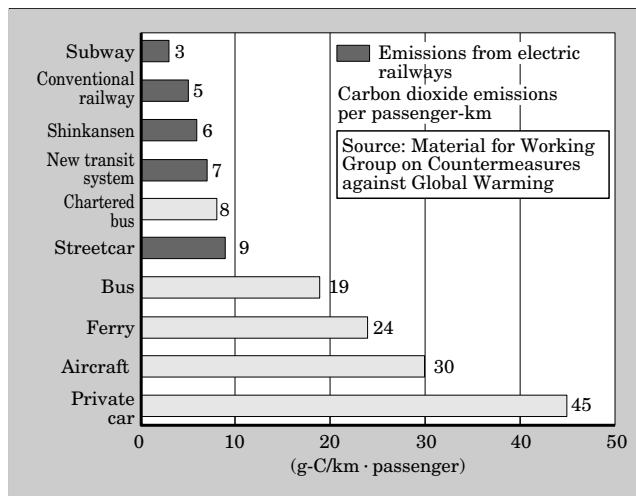
The total capacity of var compensators installed annually throughout the world is 4 to 5 GVA. Two thirds of the total installed capacity is for power supply systems, and TCR is the dominant type in this field. Introduction of the STATCOM started approximately 10 years ago, and STATCOM now accounts for several percent of the total installed capacity. The number of STATCOM installations is, however, expected to increase in the future due to its advantages such as three-phase unbalance compensation, high-speed control, compact size and non-harmonic property. In addition, a new type of var compensator provided with series-connected self-commutated semiconductors, directly connected to a power system via a reactor has been proposed and is being put into practical use, although the number of installed units is low now. Once large-capacity, high-voltage self-commutated semiconductors are developed in the future, the STATCOM will surely become more popular. For details, refer to another paper, “Var Compensators,” in this special issue.

3. Power Supply Systems for Electric Railways

The total length of railways in Japan is approximately 15,000 km. Figure 4 shows the carbon dioxide emissions of various passenger transport vehicles. It is evident from the figure that electric railway vehicles emit the least amount of carbon dioxide and consume the least amount of energy as compared with other transport vehicles. An electric railway is a high-speed, mass transporting mechanism that meets the needs of the age, namely energy conservation.

Figure 5 shows electric railway feeding systems.

Fig.4 Carbon dioxide emissions from passenger transport vehicles



There are two types of feeding systems, a DC feeding system widely used in urban areas and an AC feeding system as typified by the Shinkansen Line (New Trunk Line). The AC feeding system is further classified as an AT (auto transformer) feeding system, which is the present standard, or a conventional BT (booster-transformer) feeding system. Figure 6 shows various technical challenges unique to electric railway systems. Most of these challenges were solved by the power electronics technology.

3.1 DC electric railway

Major challenges for DC electric railway power supplies are surplus-power regeneration and environmental protection.

(1) Surplus-power regeneration

Electric trains provided with inverters for regenerative braking have become commonplace. Regenerated electric power is, however, not always effectively utilized for powering trains because the loads are random and mobile, sometimes resulting in the loss of regenerative braking during intervals when the train schedule is not busy. The loss of regenerative braking has been indicated as a factor that may prevent the effective use of regenerated energy, be counterproductive to attempts to reduce the maintenance of brake shoes, and moreover may obstruct the highly accurate position stopping function in automatic train operation. As a result, regenerated energy absorbers are increasingly being installed on the ground side.

(2) Environmental compatibility

To meet such requirements as smaller size and maintenance-free operation, vaporization-cooling systems have been used with silicon rectifiers, the main components in DC substations, for over 20 years. These systems have been using CFC (chlorofluorocarbon) or PFC (Parfluorocarbon) as the cooling medium. These media were, however, specified as environment-disrupting substances conducive to ozone layer deple-

Fig.5 Electric railway feeding systems

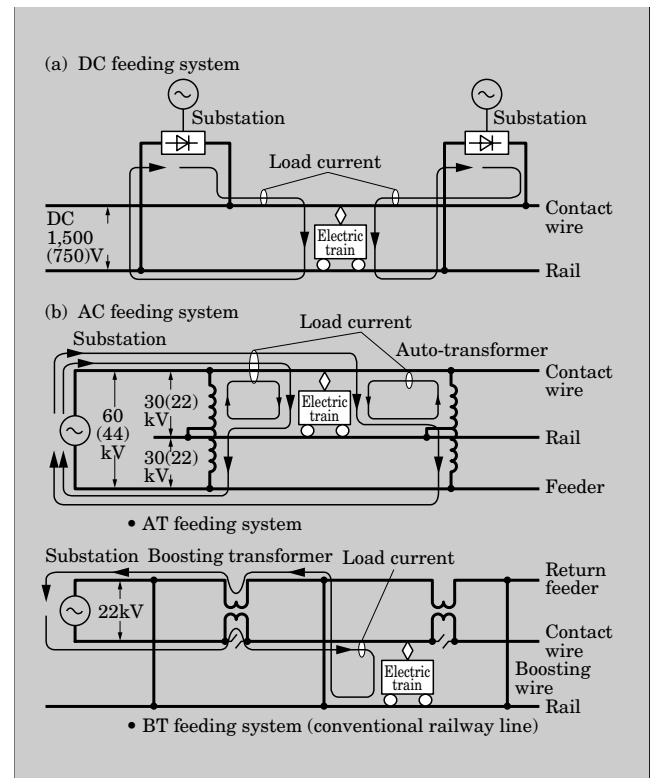
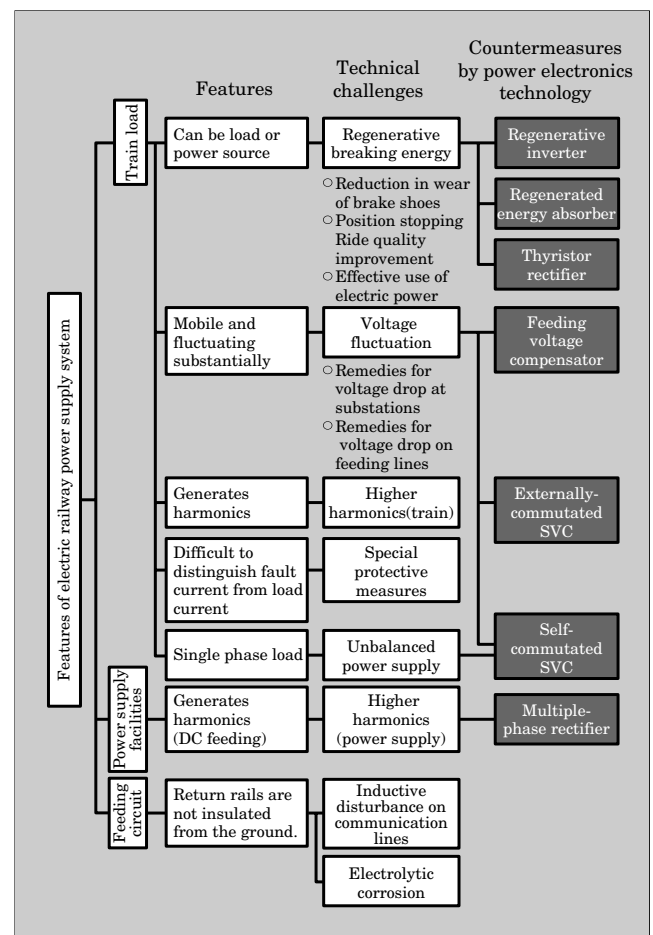


Fig.6 Technical challenges unique to electric railways



tion and global warming in The Montreal and Kyoto Conferences. To fundamentally resolve these environmental problems and to realize much smaller size and higher efficiency, Fuji Electric has developed and commercialized an innovative new-type vaporization-cooling silicon rectifier using pure water as the cooling medium.

3.2 AC electric railways

A typical challenge in AC electric railways is the implementation of countermeasures against voltage drop on the feeding lines, and the unbalance between phases on the power supply side caused by mobile, single-phase train loads. Particularly, in the Tokaido Shinkansen Line, which has the heaviest train load, var compensators utilizing power electronic technology have been introduced to solve these problems.

4. Future Prospects

The power supply system consists of three components: a power unit, controller and supervisory unit.

Today, most power units contain self-commutated semiconductors, and the units can easily generate voltage and current suitable for users' needs and load conditions. As a result, dramatic improvement in productive efficiency can be expected, reactive power and harmonics can be suppressed, and the utilization factor of the power supply can be improved, yielding great benefit to users.

Power semiconductors will continue to be improved in the future. If SiC semiconductors become commercialized, they will enable dramatically higher-speed and lower-loss operation of power units, thereby improving efficiency, reducing the necessity for heat exchangers, and consequently expanding the application range of power supply systems.

Controllers will be made smaller in size and higher in performance.

Supervisory units use an HMI (human-machine interface) to facilitate operation monitoring and the collection of maintenance information. In the future, the operating conditions of various devices, maintenance information and failure records will be monitored by the manufacturer via the Internet, allowing various parameters to be changed, preventive maintenance measures to be recommended and the implementation of quick restoration from failures.

In the past, the three components of power supply systems—power units, controllers and supervisory units—have been made with higher capacity, more enhanced functions and higher reliability, contributing to improved productivity, energy saving and low cost in equipment and plants. Additionally, for the future, excellent environment-friendliness is required. For

example, CFC, which had been used for many years as the cooling medium for power units, was replaced by PFC, a more environment-friendly cooling medium. Recently PFC is being replaced by pure water, which is harmless to the environment. Low-acoustic noise power supply systems using high-speed power semiconductors are in widespread use. In addition, power converters free from reactive power and harmonics are increasingly being used to effectively utilize electric energy. Thus, power supply systems will be developed based on four key concepts of “higher capacity,” “higher level functionality,” “higher reliability” and “excellent environment-friendliness.”

How will energy consumption change in the 21st century? Growth in demand for electric power has been sluggish due to the promotion of energy conservation and a stagnant Japanese economy in recent years. Electric power will, however, remain a dominant energy source because it is clean, safe and flexible. The use of fossil fuels as a direct energy source for engines and other applications is restricted because they are considered to be chief causes of air pollution. It will take a long time before nuclear fusion energy can be used as a daily energy source because its control technology is not yet established. Biogas energy is still under development. Utilization of natural energy such as solar and wind will surely increase, but it is limited in quantity and is basically transformed into electric power before application.

In recent years, power generation has increasingly become distributed. The installation of distributed power supplies requires consideration of their effects on power systems, because they are relatively small in scale. Particularly, distributed power supplies require the installation of electric power storage equipment to ensure electric power quality, and the control of distributed power supplies based on the network performance of power systems. The wireless transmission of electric power can be cited as a future technology, however its implementation will require examination of the role of the power supply and of a suitable configuration for this technology.

5. Conclusion

Power supply systems have been utilized for a wide range of applications for many years. Electric power will undoubtedly remain a safe, convenient energy source in the future. There are, however, many challenges to be overcome. To meet market needs, Fuji Electric has determined to do its best to develop and provide easy-to-use, clean power supply systems utilizing its accumulated expertise along with new innovation.



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