Business Operation and Global development of Instrument Transformers in NISSIN

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Synopsis

Nissin Electric Co. (Nissin) started its instrument transformer business in 1952, with the commercialization of capacitor voltage transformers (CVT). We subsequently commercialized current transformers (CT) in 1954 and gas-insulated voltage transformers (gas VT) for GIS in 1978. These three types of instrument transformers comprise the mainstream of current transformers business.

In accordance with the decrease of domestic instrument market in Japan, we shifted to overseas manufacture. At first CVTs joint venture business more started in China in 1995. Next Gas-VTs business for GIS more established as independent capital in 2002. Finally CTs business more established in 2004.

This paper describes the history and future prospects of our instrument transformer business.

1. Introduction

Electric power systems (power generation, transmission and distribution) have expanded in scale along with economical growth the progress of the economy. Substations have been distributed widely and complicated to enhance the convenience of human's life. High-advanced distributing information system is essential for effective control and protection of these substations. Instrument transformers which applied to exact measurement, control and protection systems with highly reliable voltage/current information, cover a key role in operating electric power systems without trouble, thereby ensuring a high-quality electric power supply.

Nissin has manufactured 22 kV ~ 1,100 kV CVTs, Gas-VTs, CTs and other related equipments, and has already delivered them to customers in 55 countries.

Now, Nissin manufacture instrument transformers in three countries: Japan, China and Spain. We are developing our instrument transformer business at these manufacturing bases in accordance with our philosophy of manufacturing in the most appropriate country using materials procured from the most appropriate country. The history of the commercialization and manufacturing base of our instrument transformers and supply record are shown in **Tables 1** and **2**, respectively.

2. Capacitor Voltage Transformer (CVT)

Among our instrument transformers, CVTs have been on the market for the longest time, with the largest sales volume. A CVT uses the intermediate voltage of a capacitor volatage divider which is reduced to the appropriate voltage for inductive intermediate voltage transformer. Since a CVT has high insulation reliability and increases its cost-effectiveness in comparison to a inductive VT as voltage increases, CVTs are widely used in 110 kV or higher voltage open-type substations.

Since its commercialization of a 154 kV CVT in 1952, Nissin has worked to improve its characteristics and reduce its price to increase its appeal for our customers.

CVTs were initially used to detect voltage. We employed our original technologies to improve CVT frequency characteristics, transient response (memory action), ferroresonance and error fluctuation due to hollow porcelain insulator surface contamination. We also stabilized withstand voltage due to hollow porcelain insulator contamination and increased earthquake resistance. In addition to these performance improvements, we added a secondary short-circuit protector and relay malfunction preventive device, to meet customer needs in Japan. As a result, application of our CVTs expanded to relays and electric power supply and demand control systems. In 1970, we enjoyed a nearly 100% CVT market share in Japan.

When 500 kV power transmission systems commenced operation in Japan in 1971, all electric power companies used our CVTs in their facilities. To meet the orders from these companies, in 1970 we built a CVT manufacturing plant in Maebashi. At the same time, we built an ultrahigh-voltage test laboratory to carry out 800 kV devices withstand voltage testing and partial discharge measurement without any influence from external noise.

*Power Equipment Business Unit

Table 1　Progress of Instrument Transformer Business and Manufacturing Base

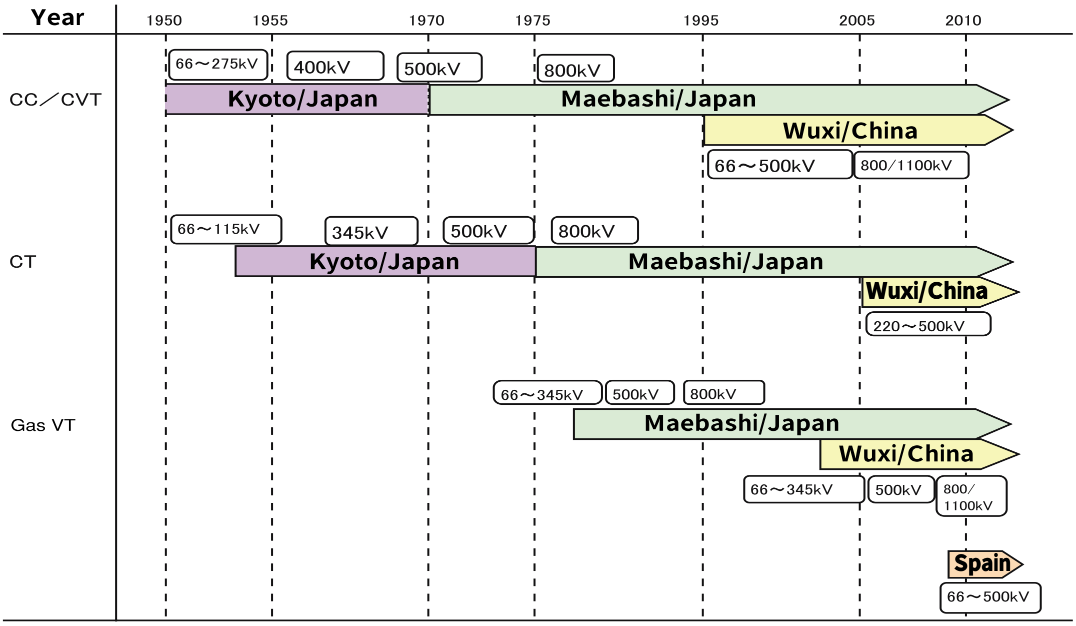


Table 2　Supply Record of Instrument Transformer

Type	Place of manufacture		Voltage [kV]	～1990	1991～1995	1996～2000	2001～2005	2006～2010	Subtotal	Grand total
CVT	Japan		33 and below	1,875	84	40	51	22	3,947	57,841
			66～138	25,520	2,342	1,515	915	1,029	31,321	
			154～275	16,399	1,205	953	840	773	20,170	
			330～420	917	0	19	42	31	1,009	
			500 and over	1,208	36	86	14	50	1,394	
	China		Less than			23	722	2,003	2,748	44,778
			66110			1,042	7,645	11,986	20,673	
			220			883	5,684	8,429	14,996	
			330			0	78	302	380	
			500 and over			65	1,996	3,920	5,981	
CT	Japan		33 and below	10,069	441	666	288	439	11,903	32,364
			66～138	10,278	456	833	236	346	12,328	
			154～275	4,639	773	539	445	338	6,734	
			330～420	697	11	3	49	79	839	
			500 and over	241	58	93	141	27	560	
	China		110 and below				0	15	15	268
			220/230				0	18	18	
			330/420				0	116	116	
			500 and over				45	88	133	
Gas VT	Japan	Single phase	33 and below	35	11	14	27	10	97	16,200
			66～138	2,571	2,515	2,394	1,381	2,237	11,098	
			154～275	375	124	228	277	709	1,713	
			330～420	271	266	517	757	915	2,726	
			500 and over	77	156	147	74	112	566	
		Three phase	33 and below	30	152	339	204	221	946	7,367
			66～187	1,325	1,002	1,015	1,065	1,931	6,348	
			220～275	8	35	17	12	1	73	
	China	Single phase	66～110				350	2,825	3,175	10,344
			220				792	5,868	6,660	
			330				18	243	261	
			500 and over				8	240	248	
		Three phase	66～110				379	2,859	3,238	3,238

A CVT consists of a capacitor voltage divider and an inductive intermediate voltage transformer with compensating reactor.

Although the inductive intermediate voltage transformer with compensating reactor that is electromagnetic unit has remained almost unchanged, the insulation performance of the capacitor unit has been remarkably improved. For CVTs supplied to domestic customers from 1952 (the year our CVT was commercialized) to 2006, a dielectric comprising kraft paper (60 μm thick) immersed in mineral oil was used. In 2007, the dielectric was replaced with one comprising synthetic polymer Film immersed in synthetic oil. For export CVTs, a dielectric combining kraft paper (25 μm thick) and mineral oil was used from 1967 to the first half of 1980. Since the second half of 1980, a dielectric comprising kraft paper and polypropylene film immered in synthetic oil has been used.

When compared with CVTs made by overseas makers, our CVTs are provided with unique features to meet the needs of Japanese electric power companies. Typical examples of such features are described in the following sections.

2. 1 Characteristics of CVT

2. 1. 1 Minimization of Error Due to Contamination

A CVT capacitor is housed in a hollow porcelain insulator. For a high-voltage CVT, two or more insulators are stacked one on another, as shown **Fig. 1**. For a CVT of normal structure, if the hollow porcelain insulator surfaces get wet and are contaminated, a leakage current will flow into or out of the capacitor and deteriorate the CVT's error characteristic. To eliminate such adverse effect of leakage current, we developed a direct-connection type hollow porcelain insulator in which the intermediate metal bracket is insulated from the capacitor elements housed in the insulator. This new construction prevents leakage current outside the insulator from flowing into or out of the space between capacitor elements, thereby preventing error characteristic deterioration. The new construction also prevents meter indication accuracy deterioration attributable to wetting and contamination of the hollow porcelain insulator's surface, while preventing relay malfunction and wattmeter accuracy deterioration. Our CVTs, comprising the hollow porcelain insulator of the new construction, are used in Japan as the voltage sources of ultra-high precision electric energy meters for 110 kV and higher voltage electric power trading.

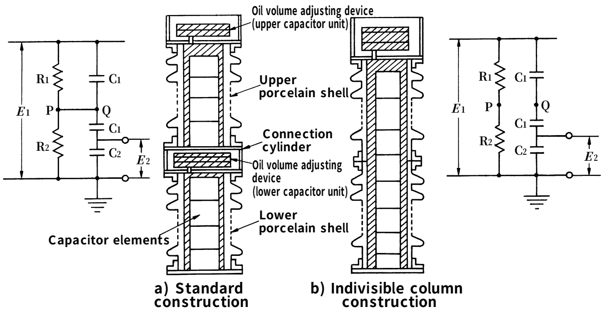


Fig. 1 Multiples Stacked Column Construction

2. 1. 2 Resonance Type Secondary Short-Circuit Protector

A reactor is used in the electromagnetic unit of a CVT, to improve its characteristics. If a secondary short-circuit occurs in the CVT, overcurrent will flow through the reactor, creating overvoltage. To protect the reactor from overvoltage, CVTs made by other companies usually have an air gap between the reactor terminals or a lightning arrestor immersed in oil. Our CVTs comprise a capacitor having the same capacitive impedance as the inductive impedance of the reactor. This capacitor is connected in parallel to the reactor through an air gap, as shown in **Fig. 2**. If a secondary short-circuit occurs, increasing reactor terminal voltage until electricity is discharged through the air gap, the capacitor will form a parallel resonance circuit that will dramatically reduce the short-circuit current. The terminal voltage of the reactor and the capacitor will increase to the intermediate voltage of the CVT, and will be stabilized at that voltage.

If a secondary short-circuit occurs in a voltage transformer, it is normal practice to immediately isolate the primary system. In contrast, use of our short-circuit protective device helps extend the CVT thermal limit to 30 minutes, up to a maximum of 2 hours. If a secondary short-circuit occurs, the system can therefore be switched to another one within this time limit, helping realize stable system operation.

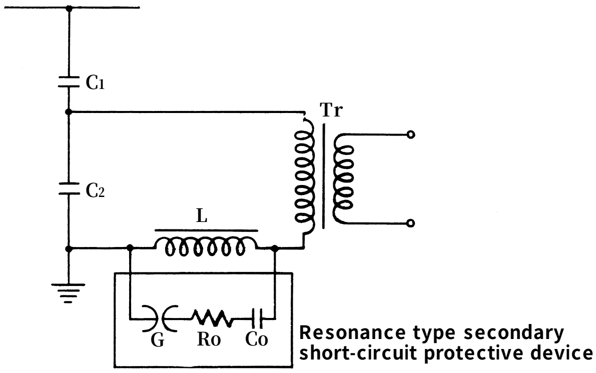


Fig. 2 Resonance Type Secondary Short-Circuit Protective Device

2．1．3 Relay Malfunction Prevention Device (CVT with auxiliary transformer)

Based on the resonance type secondary short-circuit protective device function of keeping the intermediate voltage unchanged even if a secondary short-circuit occurs in a CVT, we developed a twin EMU CVT having two independent electromagnetic units.

Twin EMU CVTs are available in two different types: type A, which has common capacitor voltage divider for both EMUs, and type B, which has individual capacitor voltage divider for each EMU.

Since a single unit of two-stage CVT produces two independent secondary voltages, it enables use of a voltage balancing relay to lock the secondary voltage of two EMUs before the system relay operates, thereby preventing erroneous tripping of the system, even if a short-circuit, disconnection or other failure occurs on the one of secondary sides of the CVT.

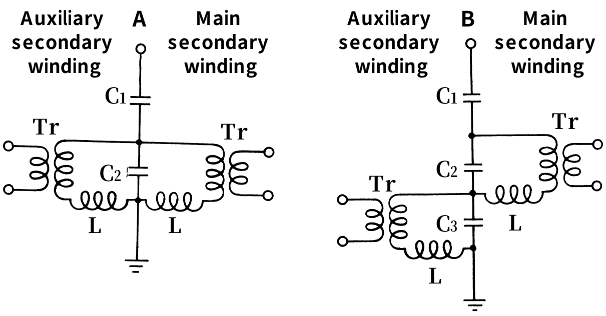


Fig. 3 Circuit Configuration of CVT with Auxiliary Transformer

2．1．4 Ferroresonance Suppression Device

Since a CVT comprises capacitors and iron core transformers connected in series, the nonlinear inductance of the iron core may create serial ferroresonance, in turn producing an overcurrent that can cause such abnormality as insulation breakdown, burnout of transformer coil, meters and relays connected to the secondary circuit; vibration or beat noise.

Various ferroresonance control measures are implemented on a trial basis. One possible measure is to design a transformer with an iron core of low magnetic flux density (0.3-0.5 tesla), and connect a resistor in parallel to the secondary circuit. However, connecting a resistor having a load equivalent to the CVT's rated load to the secondary circuit will increase CVT size and mass, making it less economical. Nissin developed the world's first ferroresonance suppression device consisting of a saturable reactor and a resistor. This device is connected in series to the secondary circuit of a CVT as shown in **Fig. 4**. We succeeded in reliably and economically suppressing CVT ferroresonance by selecting appropriate saturation voltage for the saturable reactor and resistance for the resistor, as shown in **Fig.5**.

Our ferroresonance suppression technology, which uses a saturable rector and resistor, is also used to control the ferroresonance of gas VTs, which are described in another paper.

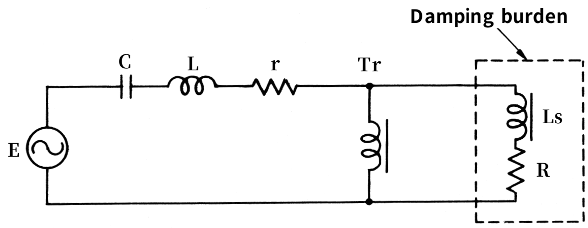


Fig. 4 Damping burden Connected to CVT

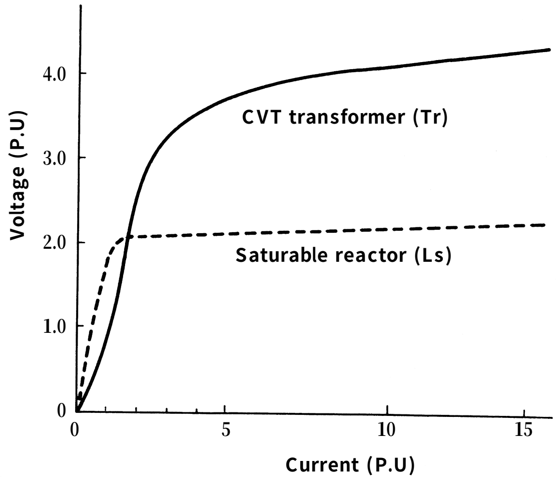


Fig. 5 Voltage versus Current Characteristic of CVT Transformer and Saturable Reactor

2．2 Earthquake Resistance of CVT

In Japan, well-known as an earthquake country, earthquake resistance is an important safety factor for electrical equipment. Until the first half of the 1960s, the earthquake resistance of electrical equipment had been designed in compliance with the architectural construction standards then in effect. Those standards required a safety factor of at least 2.5 when a static calculation assumed that a load of 0.5 G (0.5 times the mass of the subject equipment) was applied horizontally to the center of gravity of the equipment. A plan was formulated in the second half of the 1960s to transmit electric power at 500 kV. In response, to further enhance the operation reliability of electrical equipment, equipment manufacturers began to design the dynamic earthquake resistance of their equipment based on an amplification ratio that changed depending on the equipment's resonance frequency and damping characteristics. As a method for economically satisfying the severe dynamic earthquake resistance requirement for 500 kV CVTs comprising a long hollow porcelain insulator, we developed an innovative suspension type CVT, as shown in **Fig. 6**. After practical vibration resistance testing and analytical calculation of a model CVT, we put the CVT into practical use. We also developed a self-standing type 500 kV CVT, which is shown in **Fig. 7**, for use in districts where moderate earthquake resistance is required. This CVT was first delivered to a customer in 1972.

The Miyagiken-oki Earthquake struck the Tohoku Region in June 1978, causing devastating damage to electrical facilities in the region. With this disaster as a turning point, the concept of dynamic earthquake resistance design was also applied to 275 kV or lower voltage electrical equipment. In association with this, we reviewed our CVT design and carried out practical vibration resistance testing of principal CVT models. The test condition of applying to the test samples three sine waves having a resonance frequency of 0.3 G that we used as our earthquake-resistant design standard, was severer than actually observed seismic waveforms. Today, this test condition is used generally in Japan to evaluate the earthquake resistance of electrical equipment.

2．3 Contamination Resistance of CVT

Since Japanese thermal and nuclear power plants are usually located near the coast, electric substation equipment installed near these plants is prone to contamination by salt water. The withstand voltage of the hollow porcelain insulators may be degraded and cause external flashover.

"Electric Technology Research" magazine, Vol. 35, No.3 specifies the requirements for contamination withstand voltage of hollow porcelain insulators, with the criteria based on their mean diameter and equivalent salt contamination. We design our CVTs in compliance with the above criteria. In practice, since our CVTs contain the capacitor elements in hollow porcelain insulators so as to distribute the voltage

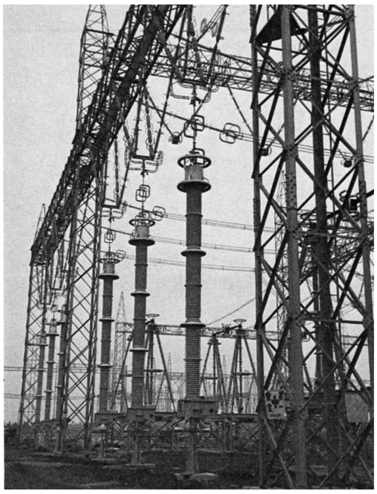


Fig. 6 Suspension Type 500 kV CVTs for Use in Heavy Contamination Districts

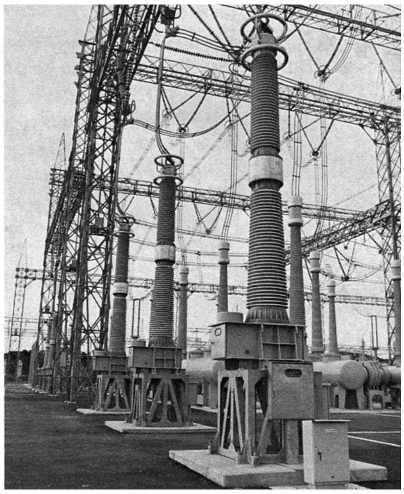
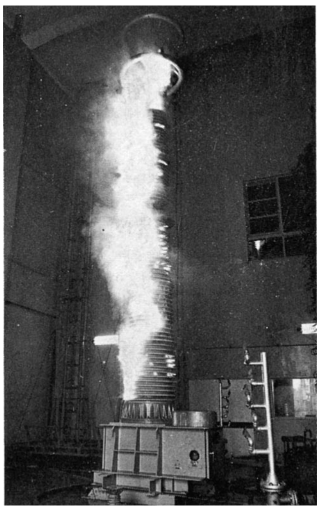


Fig. 7 Self-Standing Type 500 kV CVTs for Use in Ordinary Contamination Districts



a) Equivalent fog withstand voltage test

b) Washing withstand voltage test

Fig. 8 500 kV CVT Contamination Test evenly in the vertical direction, the chance of actual flashover attributable to contamination decreases as the degree of CVT contamination decreases. For reference, our test results showed that in CVTs containing capacitors, flashover voltage increased by approximately 30% when the density of equivalent salt contamination was 0.02 mg/cm^2, approximately 20% when the salt contamination was 0.03 mg/cm^2 and approximately 10% when the contamination was 0.12 mg/cm^2, as compared to flashover voltages of CVTs that did not contain capacitors. A 500 kV CVT contamination test is shown in **Fig. 8**.

2．4　Other Special-purpose CVTs

2．4．1　Reverse CVT for Power Supply

Photoelectric conversion-based optical fiber systems were used in the past for a power source for controlling series-connected capacitors on high-voltage insulation pedestals. However the performance of these systems deteriorated over time. To overcome this disadvantage, we use reverse CVTs equipped with a voltage-dividing capacitor on the higher-voltage side.

2．4．2　Amplifiered CVT (AMP-PD)

We developed this CVT for use in a 500 kV gas insulated switchgear (GIS), to obtain a specified characteristic by using an electronic amplifier to amplify the voltage of a voltage-dividing electrode stored in gas piping of the GIS. To protect the amplifier from the high-frequency surge characteristic of a GIS, we achieved practical use of a system equipped with a surge-shielding insulation transformer between the high-voltage circuit and amplifier, as shown in column B of **Table 3**.

This CVT had functioned in an actual electric power transmission system for about 30 years, since 1978. However this type of CVT lost popularity as gas VTs became the mainstream of voltage transformers for GISs. For 110 kV and lower voltage GISs, small amplifier CVTs shown in column A of **Table 3** are still used to detect voltage.

3．Porcelain-Clad Type Current Transformer (CT)

Nissin released its first 77 kV porcelain-clad type CT in 1954. Since then, we have increased the product models by expanding their rated voltage and current. In 1983, we exported an 800 kV/4,000 A rating CT. Structures of porcelain-clad CTs are roughly classified into three types. Their application range is determined according to their performance reliability and economical efficiency in terms of rated voltage and current. **Table 4** presents the CT classification in terms of structure, as well as their features. **Figs. 9** through **11** show photographs of typical CTs.

3．1　Characteristics of CT

3．1．1　Steady-State Error

An equivalent circuit for analyzing the error characteristics of CTs is shown in **Fig. 12**. In this figure, CT error is caused by current I_0 that flows through excitation impedance Z_0 of the iron core used. The ratio of current I_0 to secondary current I_2, I_0/I_2, or the impedance ratio of each shunt circuit, $(Z_{2\ell}+Z_b)/Z_0$, is an absolute error. The active component of the absolute error is a ratio error, while the reactive component is a phase angle error. To improve the error characteristics of a CT, it is necessary to design an iron core having a high magnetization characteristic and thereby realize a low magnetic flux density that requires the least excitation current.

Table 3　Comparison of Amplifier-Type CVTs

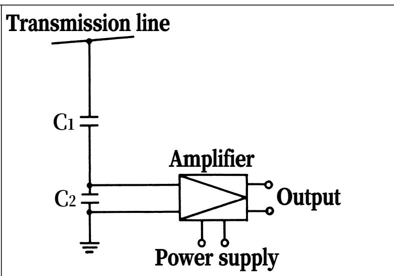
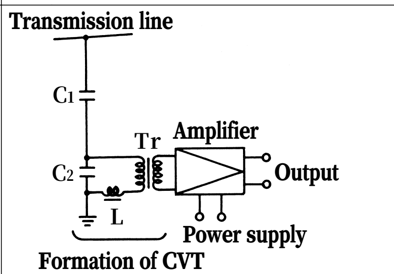
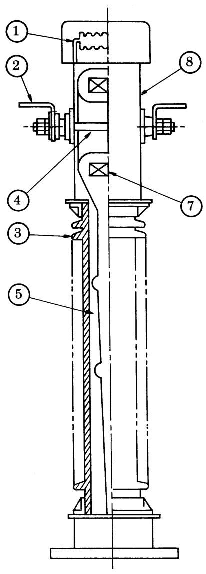
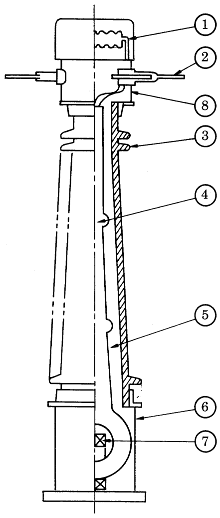
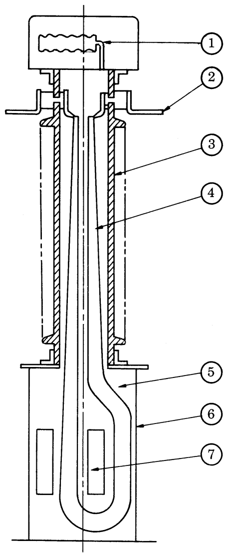
	Construction	Advantage	Disadvantage
A		1. Simple in construction 2. Superior transient and frequency characteristics 3. Small size	1. Lack of safety; susceptible to surge and noise due to non-insulation between high-voltage circuit and amplifier 2. Adverse effect on error by cable stray capacitance in parallel with C_2
B		1. Enhanced safety and insusceptibility to surge due to insulation between high-voltage circuit and amplifier 2. Insusceptible to cable stray capacitance 3. Amplifier is insusceptible to noise due to low input impedance. 4. Conventional CVT technology can be applied.	1. Transient and frequency characteristics are limited by CVT characteristic. 2. C_1 requires larger capacitance than that for A to B systems. 3. Requires additional space for CVT installation

Table 4 Comparison of CTs in Terms of Application, Structure and Features

Construction / Item	Inverted type CT	Eyebolt type CT	Hair-pin type CT
Voltage class	66～550kV	66～800kV	66～550kV
Primary current range	Suitable for use in high-current range (2,000-5,000 A)	Suitable for use in broad current range (50-5,000 A)	Suitable for use in medium current range (300-3,000 A)
Iron core/ secondary coil position	Live part in upper tank	In lower tank (grounding potential)	In lower tank (grounding potential)
Mechanical strength	Since most of the iron core, secondary coil, primary conductor and insulating materials are housed in the upper tank, the center of gravity of CT lies near the head of the hollow porcelain shell. Therefore, this construction cannot meet severe earthquake resistance requirements.	Since the primary conductor, most insulating materials, iron core and secondary coil are housed in the lower tank, the center of gravity of CT lies near the bottom of the hollow porcelain shell. This construction can therefore meet severe earthquake resistance requirements.	Like an eyebolt type CT, this construction is advantageous in meeting severe earthquake resistance requirements.
Construction drawing Components ①Metal bellows (oil volume adjusting device) ②Primary terminal pad/stud ③Hollow porcelain shell ④Primary conductor ⑤Insulating oil ⑥Lower tank ⑦Iron core/ secondary coil ⑧Upper tank			

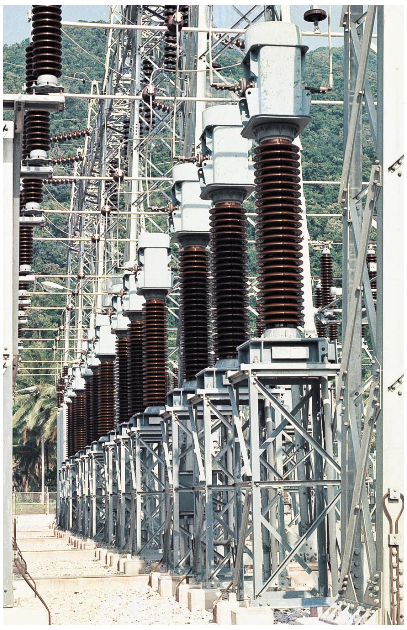


Fig. 9 115 kV Inverted Type CT 58-5

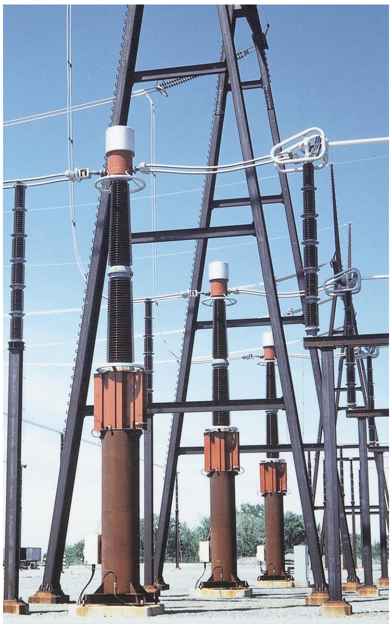
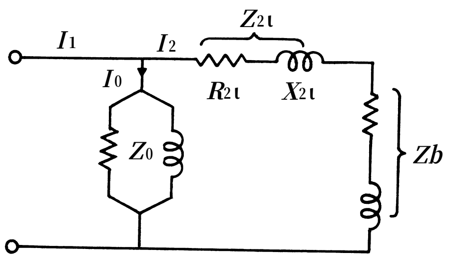


Fig. 10 800 kV Eyebolt Type CT 60-70

Fig. 11 500 kV Hair-Pin Type CT

3．1．2 Overcurrent Characteristics

For the use area of protection relay CTs, an overcurrent constant n is defined as representing the error attributable to system failure and the resulting overcurrent generation. Standards for normal CTs define overcurrent constant n as 10 or 20, the ratio of overcurrent to rated current. This means that, when the rated burden is connected, the error should not exceed 5% or 10%. An example of overcurrent characteristics is shown in **Fig. 13**.



I_1 : Primary current (A)
I_2 : Secondary current (A)
I_0 : Excitation current (A)
Z_0 : Excitation impedance (Ω)
Z_{2l} : Secondary leakage impedance (Ω)
Zb : Secondary burden (Ω)

Fig. 12 Equivalent Circuit for CT

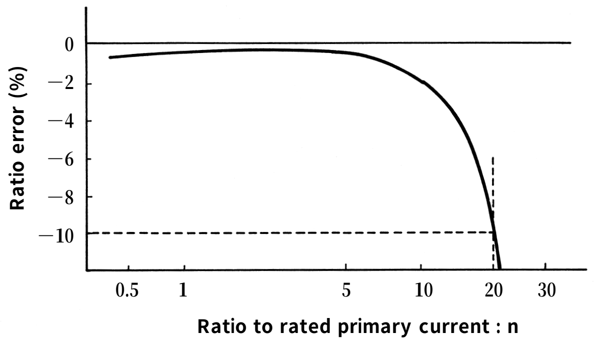


Fig. 13 Overcurrent Characteristics (for n>20)

3．1．3 Transient Characteristics

Technology for protecting ultrahigh voltage power transmission systems is advancing in terms of speed and sensitivity to failure. The characteristics of the CTs used in transmission systems must also correspond to such technological progress. In particular, such CTs are must precisely transform the fault current containing a symmetrical AC short-circuit current and a DC offset component.

Fig. 14 shows a current waveform superimposed with a 100% DC component, as observed during system failures. If this fault current flows, its direct current component will remarkably increase the magnetic flux of the iron core, as shown in **Fig. 15**. As a result, iron core

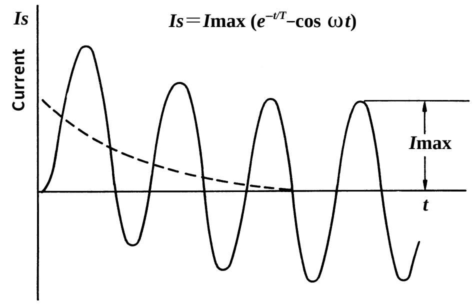


Fig. 14 Fault Current

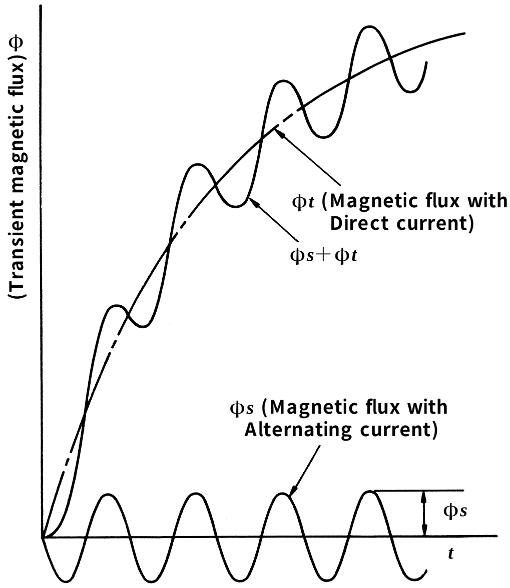


Fig. 15 Transient Magnetic Flux

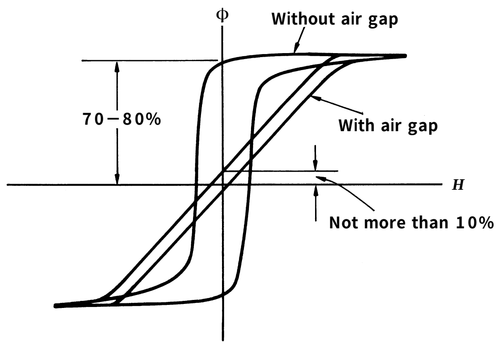


Fig. 16 Magnetization Characteristics

excitation current will increase and degrade the CT error characteristics. To avoid CT performance deterioration, the cross-sectional area of the iron core should be designed large enough that the CT will not be saturated before the protection relay operates, even in the event of system failure. After the fault current is cut off, residual magnetic flux will remain in the CT's iron core and the circuit will close again in an extremely short time. If a fault current of the same polarity flows again, the iron core will be immediately saturated, causing the secondary

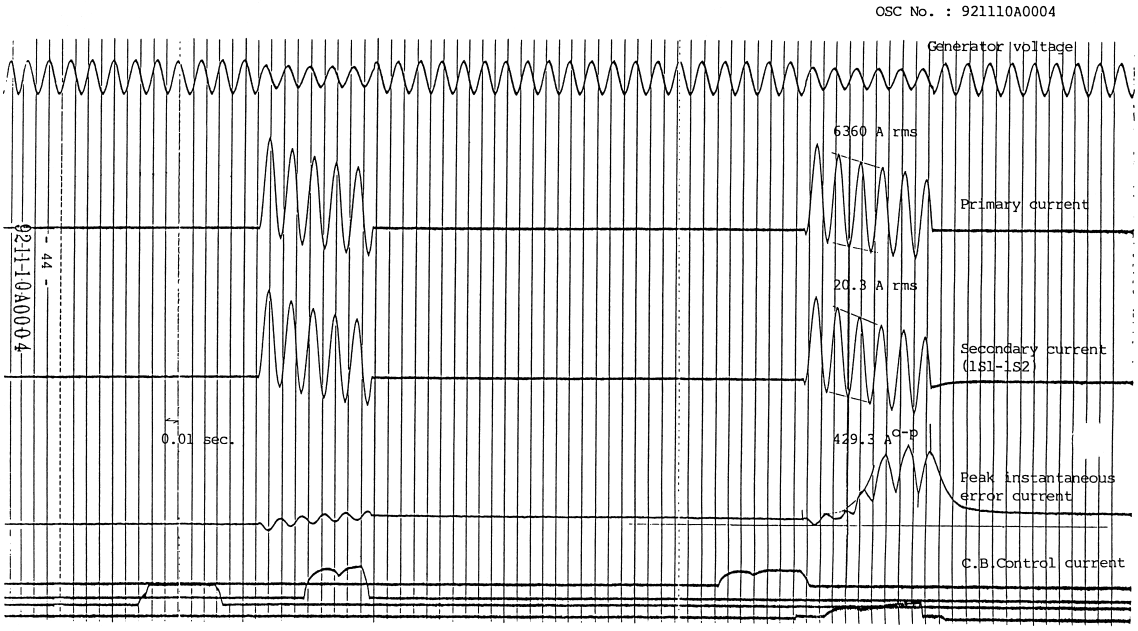


Fig. 17 Test Result for Class TPY CT

current to produce a large error. To minimize the residual magnetic flux, the general practice is to provide the iron core with an air gap appropriate for the magnetic circuit. The difference in magnetization characteristics between CTs with and without an air gap is shown in **Fig. 16**. The transient characteristics of CTs are defined in IEC60044-6. The following items are specified for the severest Class TPY specifications.

①Time constant of primary circuit, ②specified duty cycle (C-O-C-O), ③first close time, ④first error determination time, ⑤reclosing interval, ⑥second close time, ⑦second error determination time

Fig. 17 shows the result for Class TPY CT under the conditions of ①100 ms, ②C-O-C-O, ③100 ms, ④40 ms, ⑤400 ms, ⑥100 ms, and ⑦40 ms.

3．2 Temperature Rise

A CT installed in a power transmission system is directly exposed to the system current. As a result, the CT is heated by stray loss resulting from ohmic dissipation and electromagnetic excitation by the system current. The resulting CT temperature increase is an important factor for CT design. Although in the past it was difficult to estimate CT temperature rise at the design stage, recent progress in analysis technology has made it possible to estimate CT temperature rise with considerable accuracy at design stages.

3．3 High-Frequency Surge Test

In foreign countries, CTs occasionally failed as a result of the generation of oil-dissolved gases or flash-over. Since these failures were caused by repetitive exposure to switching surge and lightning surge and resulted deterioration of CT's insulation performance, the applicable IEC Standard recently specifies an additional requirement that test CTs be exposed to a specified number of cycles of a chopped wave.

Our CTs are equipped with an electrode comprising capacitor cones that prevent electric field concentration. These CTs are also tested for partial discharge by a high-sensitivity discharge measuring system. Owing to these failure-preventive measures, our CTs have not caused any serious failure in actual electric power transmission systems. For ultrahigh voltage CTs, we conduct CT-type approval testing in compliance with the IEC Standard, to confirm that the CTs do not generate any oil-resolved gas.

4．Gas-insulated Instrument Transformer (Gas VT)

The gas insulated switchgear (GIS) was first used in Japan in the 1970s. Since then, GISs have rapidly increased in popularity because of their usability on remarkably restricted substation premises, their high earthquake resistance, high salt damage resistance and simplified maintenance procedures.

During the initial stage of voltage transformer use for GISs in Japan, molded VTs were used for low-voltage GISs, amplifier type CVTs were used for high-voltage GISs and special-purpose oil-filled CVTs were used for full-voltage GISs. However, the molded VTs lacked insulation reliability, because they often formed voids or cracked. With amplifier type CVTs, surge suppression measures were difficult to implement and a stable power source was required, resulting in economic disadvantage in the voltage range of 66 kV to 220 kV. On the other hand, oil-filled CVTs, which were developed especially for GIS use, offered high insulation reliability but were large and heavy. They were also unsuitable for fireproof GISs because they contained oil. In the meantime, Japanese GIS manufacturers became interested in the first use of gas VTs in European countries, in around 1975. Nissin entered into technical collaboration with MWB, a leading gas VT maker in West Germany (at that time), initiating the manufacture of gas VTs in 1977.

After the technical collaboration agreement with MWB expired in 1987, we started to develop our original gas VT technologies. In 1998, we first supplied a gas VT for an 800 kV GIS (**Fig. 18**) to our customer in Korea. In the first half of 2011, we exported a UHV gas VT to China. This gas VT will be installed in the first 1,100 kV GIS (**Fig. 19**) in China.

Fig. 18 800 kV Gas VT 2000-77

Fig. 19 Operation Test of 1,100 kV Gas VT

We improved the traditional oil-filled gas VT by replacing the coil interlayer insulating paper with plastic film and the oil with SF_6 gas. As with GIS, the new gas VT allows insulation coordination, while its size and mass are substantially less than a CVT. **Figs. 20** and **21** schematically show the structure of a single-phase gas VT and a three-phases-in-one-enclosure gas VT, respectively.

New gas VT operation is highly reliable and resolves the problems associated with the old gas VTs. Typical examples of past problems and their solutions are described below.

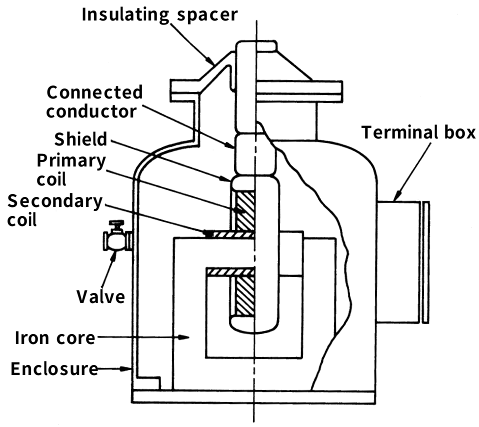


Fig. 20 Internal Structure of Single-Phase Gas VT

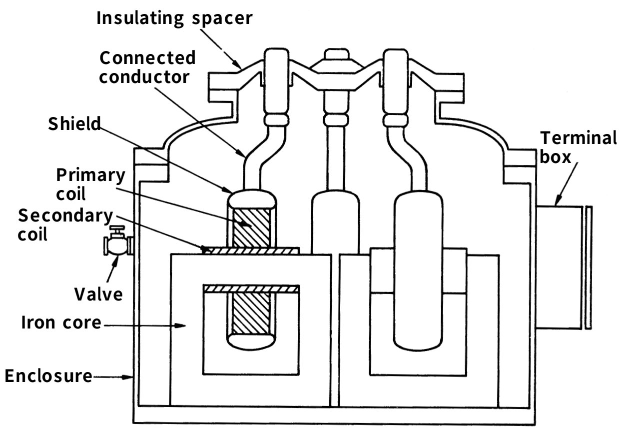


Fig. 21 Internal Structure of Three-Phases-in-One-Enclosure Gas VT

4．1 Mechanical Strength of Coil

Since a gas VT uses low friction plastic film for interlayer insulation of the coil, the coil exhibits low friction and is easily dislocated. In the past, some gas VT coils dislocated due to shock during transportation or installation. For a three-phases-in-one-enclosure gas VT, the coil was dislocated by the electromagnetic force of the current produced at release of the power line discharge. To eliminate such abnormalities by sufficiently increasing friction against the coil layers, the plastic film is coated with an epoxy resin adhesive.

4．2　Protection from Power Line Potential Discharge

For a gas VT located on the power line side of a GIS, if the line breaker is opened, the line will release the electric charge it has stored through the primary coil of the VT. A power cable transmission system or a long distance high-voltage line in particular will discharge an extremely large quantity of electric energy. In such case, the iron core of the VT will be saturated when the electric charge is released, causing an extremely large current to flow through the primary coil. An extremely large number of ampere-turns will then create intensive electromagnetic force inside the coil or between the phases, in the case of a three-phase VT. If a large current flows through the primary coil, the winding will experience extreme heating. It is therefore essential to check the maximum allowable electric discharge given in the VT specifications.

If a suspended power transmission line is struck directly by lightning discharge for comparatively a long time, which is often observed in Japan during winter, additional large electric current will flow through the primary coil of each VT. The increased electromagnetic force may cause coil abnormality. Our gas VTs have been equipped with appropriate protection against lightning.

4．3　Protection of Gas VT from Ferroresonance

If power system voltage is divided by a capacitor, the gas VT used in the system will form a circuit similar to that of a CVT; this may cause ferroresonance phenomena.

In parallel transmission lines consisting of higher and lower power lines of different voltages, capacitance C_1 is formed between the higher and lower level power transmission lines connected with a VT, while capacitance C_2 is formed between the lower level power transmission line and the earth. The electric circuit is equivalent to that of a CVT, as shown in **Figs. 22** and **23**.

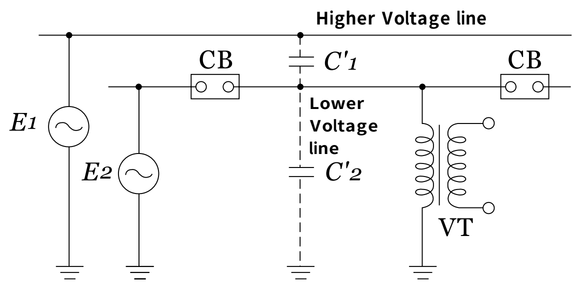
For a bus line VT, capacitance C_1 is formed between the VT and the power supply when the capacitor (equalizer capacitor of multibreak circuit breaker or capacitor for improving SLF) connected between the poles of the circuit breaker is disconnected, while capacitance C_2 is formed between the bus line and the conduit line kept at the grounding potential. The electric circuit is equivalent to that for a CVT, as shown in **Figs. 24** and **25**. ferroresonance preventive measures are described in detail in another paper.

4．4　Reducing Secondary Transmitted Surge

In the past, an extremely high frequency surge was produced when the circuit breaker of a GIS was opened/closed; this surge moved to the secondary side of the gas VT, causing abnormalities in the CVT's secondary circuit and the instruments and relays mounted in the VT. To eliminate these troubles and thereby meet the requirements of the IEC Standards, we installed a shielding plate and improved the performance of the electric wires laid on the secondary side. We also established an extremely high frequency voltage measuring technique, after several experiments.

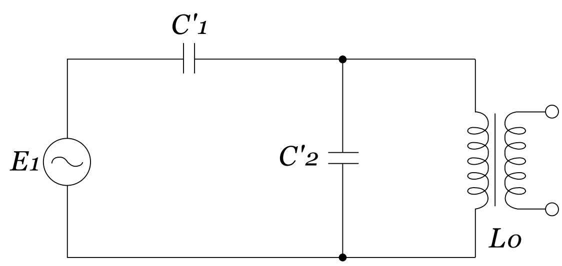
4．5　Gas VT Equipped with Isolating Device

When it was necessary to apply high AC voltage to a GIS in field testing, the iron core of the gas VT was often saturated, preventing further application of voltage. Since isolating the VT from the GIS involves time-consuming procedures, our customers and GIS manufacturers asked us to establish an effective measure. In response, we developed a gas VT equipped with a isolating device. This special purpose gas VT is described in detail in another paper.



C'_1 : Capacitance between Higher and lower Voltage lines
C'_2 : Capacitance between lower Voltage line and earth
E_1 : Power supply for Higher Voltage line
E_2 : Power supply for lower Voltage line

Fig. 22　Schematic Illustration of Double Power Transmission Line



L_0 : Magnetic exciting inductance of VT

Fig. 23　Equivalent Circuit

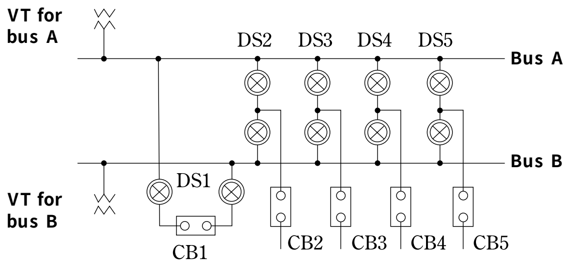
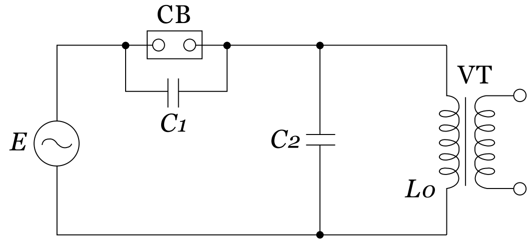


Fig. 24 Bus Configration



E : Power supply voltage
CB : Circuit breaker
C_1 : Capacitance between circuit breaker's electrodes
C_2 : Capacitance between bus and earth
VT : Gas-insulated VT
L_0 : Magnetic exciting inductance of VT

Fig. 25 Equivalent Circuit

5. Global Expansion of Instrument Transformer Business

5.1 China

5.1.1 CVT

Nissin commenced overseas manufacture of CVTs in 1995, at Nissin Electric Wuxi Co., Ltd., a joint company between Nissin and China Electric and Capacitor Co. Ltd., a Chinese government-owned company located in Wuxi. This company was our third overseas manufacturing base after those in Thailand and Taiwan. Inside our company there were arguments for and against the project for constructing a manufacturing base in China. At the time of the project feasibility study (FS), China was politically under a communist system and its economy was at the initial stage of transition to a capitalistic system. After continued tough negotiations with the responsible Chinese authority, both parties agreed on the establishment of our manufacturing base. We believe that our participation in the Chinese market was timely in view of the recent increase in electric power consumption in China. Although both parties insisted on owning a larger share, we finally agreed to invest in the new company on a fifty-fifty basis. Both parties also agreed to manage the company under a Chinese chairman of the board of directors and a Japanese chief executive director. The new company started with the manufacture of Chinese original products on an OEM basis, then designed new CVTs, using Nissin's technologies to manufacture them using materials made in China. After acquiring Chinese type approval of the newly designed CVTs, in 1997 the company started gradually shifting the previous models to the new models. In 1999, the company switched all its products to CVTs designed by Nissin. At the same time, the factory management system was switched from the conventional government-owned company scheme to the Japanese-style management scheme.

The change over time in number of CVTs manufactured at our factory in China is shown in **Table 2**.

The factory increased the volume of CVT manufacture from approximately 500 units per year in the early years after construction to 1500 units in 2000. During the same year, we built another factory on the joint company's premises. Since 2003, we have enjoyed a CVT market share of approximately 40% in China, while increasing the volume of manufacture to 4,000 units in 2004. Since customer demand for our CVTs is expected to increase further, we built a new CVT manufacturing factory in 2002 on the premises of the gas VT manufacturing plant we had newly constructed in the industrial park in Wuxi New District, Wuxi City, and relocated the then-existing CVT manufacturing facilities to the above new factory. In and after 2005, we manufactured more than 5,000 CVTs at the new factory.

In the meantime, we developed a 750 kV CVT (**Fig. 26**) in 2004 and a UHV (1,100 kV) CVT (**Fig. 27**) in 2009, in response to the increase in electric power transmission voltage in China. Chinese engineers we fostered were responsible for most of the development activities, though Nissin engineers dispatched from Japan were partly involved.

Fig. 26 750 kV CVT

Fig. 27 1,100 kV CVT

5．1．2 Gas VT

Nissin exported 110 kV and 220 kV gas VTs to Chinese GIS manufacturers before 2000. Based on our estimation that the market demand for GISs in China would increase dramatically, as well as our miraculous success in the CVT business in China, in April 2002 we founded a wholly owned gas VT manufacturing company, Nissin Electric Wuxi Co., Ltd. (NEW), in Wuxi National Hi-Tech Industrial Park.

As of 2002 there was no other foreign-affiliated company than our company that could supply gas VTs for GISs in China. We increased the amount of orders steadily, because our gas VTs were highly reputed, by both old and new customers (GIS manufacturers) in China.

To achieve the same level of product quality as we achieved in Japan, we brought the necessary manufacturing facilities, inspection systems, and materials into China from Japan. After our products had passed the Chinese national type approval tests, we commenced full-scale gas VT manufacture in China in 2003. The number of gas VTs we have manufactured in China since is given in **Table 2**.

The new company initially manufactured 110 kV and 220 kV gas VTs as its main products. As the voltage of made-in-China GISs increased, the company added 330 kV, 500 kV and 800 kV gas VTs to its product line, developing its manufacturing capability until in 2010 it could manufacture UHV (1,100 kV) gas VTs (**Fig. 28**). Since the then-existing factory did not have manufacturing facilities capable of making 800 kV and 1,100 kV gas VTs, in 2010 we built a new UHV gas VT factory on the company premises. The appearance of the new factory is shown in **Fig. 29**.

During several years after establishment of the new gas VT manufacturing company, we supplied gas VTs to six customers, including major GIS manufacturers managed by the Chinese government and Japanese-affiliated GIS manufacturers. The number of GIS manufacturers in China is increasing each year. Today, we supply gas VTs to nearly 15 GIS manufacturers in China. Our affiliated company and one other foreign-affiliated company held 90% of the gas VT market share in 2003. Chinese domestic gas VT manufacturers are becoming more competitive; some GIS manufacturers have started to manufacture gas VTs by themselves. In such circumstances, the Chinese gas VT market conditions are changing rapidly.

Fig. 28 1,100 kV Gas VT

Fig. 29 Ultra-high Voltage Gas VT Manufacturing Plant

5．1．3 CT

Nissin continued to export mainly 500 kV CTs to China until 2004, when the manufacture of gas VTs in China entered a growth path. In the same year, we planned the manufacture of CTs also in China. A CT is a series device that cannot be easily separated from the electric power transmission system. Taking into account the fact that many CTs made by other companies had exploded in Europe, U.S. and China, we endeavored to impart sufficient insulation reliability to CTs. The most important aspect in achieving this was to sufficiently insulate the primary conductor that would be exposed to high voltage. We started to manufacture 500 kV CTs in China by making their main bodies in Japan, vacuum-packing them and transporting them to China in special-purpose cargo-containers. In China, these bodies were assembled with domestically made accessories. From 2005 to 2010, we manufactured 268 CTs and delivered them to our customers in China, as shown in **Table 2**.

Recent appreciation of the Japanese Yen has increased the cost of importing the most important CT bodies from Japan to China, making it difficult for us to receive purchase orders for CTs. Unlike CVTs and gas VTs, CTs are manufactured by several hundred companies in China. In view of the facts that these companies are confronting severe price competitions, and that 220 kV and lower voltage CTs are purchased with priority on price rather than quality, we are planning to stop selling CTs in China, and to manufacture there CTs ordered from ASEAN member nations. These CTs are manufactured in Japan at present.

5．2 Business Expansion in Europe (Spain)

In Europe, EU member states in particular, most instrument transformer manufacturers are affiliated with large electric companies. Such industrial infrastructure has prevented us from marketing our instrument transformers in those regions. Arteche Co., a Spanish medium-scale instrument transformer manufacturers, manufactures many oil-insulated CTs, CVTs, VTs and molded transformers, but does not manufacture gas VTs for GISs. Nissin and Arteche established a joint partnership company (Arteche Nissin SL) to supply 500 kV and lower voltage gas VTs to GIS manufacturers in EU member states and other European countries, including Russia. We completed construction of a plant in the first half of 2011, and have started to manufacture gas VTs in Spain.

Fig. 30 ANSL's Plant in Spain

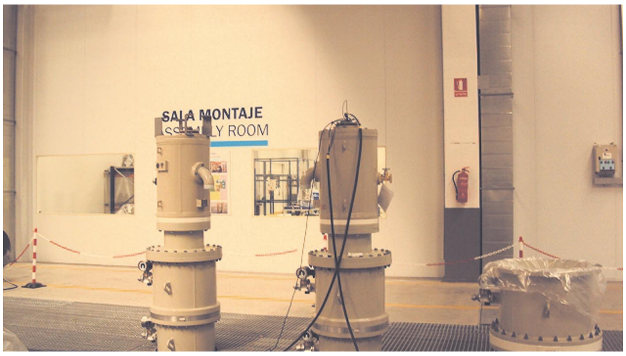


Fig. 31 Gas Manufacturing Facilities of ANSL's Plant

6．Epilogue

Nissin has continued to upgrade its design function, manufacturing equipment and performance verification systems to develop and supply instrument transformers (CVTs, CTs and gas VTs) for use in the world's highest voltage power transmission systems.

Our design department makes full use of various advanced analysis techniques for electric field, earthquake-resistance strength and heat flow, in order to promote product design most efficiently. Our manufacturing facilities and inspection systems have been automated with the latest man-machine interfaces, and consume the least necessary energy. These facilities and systems help us manufacture stable quality products. Our test laboratory in Japan is preparing to acquire globally recognized STL certification by the end of 2011.

In the years ahead, we will promote our business globally at three manufacturing bases in Japan (Maebashi, Gunma prefecture), China (Wuxi, Jiangsu Province) and Spain (Vitoria).

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