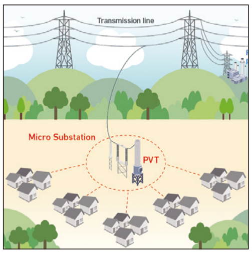


Large-Capacity PVT Utilization for a Micro Substation Capable of Directly Obtaining Low-Voltage Power from High Voltage (66 kV)

Kentaro OKA*, Yoshimune TAKAHASHI, Naoko MAKI, Masaki MURAI, Gaku HIRAMOTO, and Satoshi MIZUNO

In developing countries, many areas still exist where the distribution network is weak, making stable power supply a challenge. Therefore, focusing on the fact that transmission lines exist even in many such regions, we have developed a micro substation*1 capable of directly supplying low-voltage power using a large-capacity power voltage transformer (PVT).*2 In June 2025, we began demonstration tests of the micro substation that we introduced in India.
This project was conducted as an international demonstration project (JPNP 93050) under the auspices of the New Energy and Industrial Technology Development Organization (NEDO).[(1), (2)]

Keywords: power voltage transformer (PVT), micro substation

1. Introduction

In emerging economies, there are still many areas with underdeveloped power distribution networks, making stable power supply a challenge. Even in such areas, nonetheless, it is often the case that transmission lines are in place.

In such areas, a micro substation*1 can be a valid solution, in which a power voltage transformer (PVT)*2 is used to supply low-voltage power directly from transmission lines. This technology was proposed to a power company in India, one of the major emerging countries, and received strong positive feedback.

Focusing on a demonstration test being conducted in India, in which market needs potentially exist, this paper reports on the validity of a micro substation with a PVT, which is capable of supplying low-voltage power from high voltage (HV)*3 transmission lines to a small group of consumers without the need for a distributing substation.

2. Micro Substation Concept

2-1 Overview

The construction of a conventional substation or the installation of a diesel generator is a common means of supplying power to small-scale consumers in regions with underdeveloped distribution networks. However, to construct a conventional substation, a large installation space and substantial equipment costs are required. Diesel power generation involves high operating costs due to fuel transport and regular maintenance. Moreover, diesel power generation emits large amounts of carbon dioxide (CO_2).

In response to these challenges, Nissin Electric Co., Ltd. proposed a substation designed to supply about 100 kVA of power from 66 kV or higher HV transmission lines to (low-voltage) consumers, using a PVT with increased capacity for supplying power, which makes use of voltage transformer*4 technology intended to measure HV. Figure 1 provides a rendered image of supplying power from a micro substation; the system enclosed in the dotted-line box (containing a lightning arrester (LA), protective devices / switchgear, a PVT, and a distribution box) is termed the micro substation.

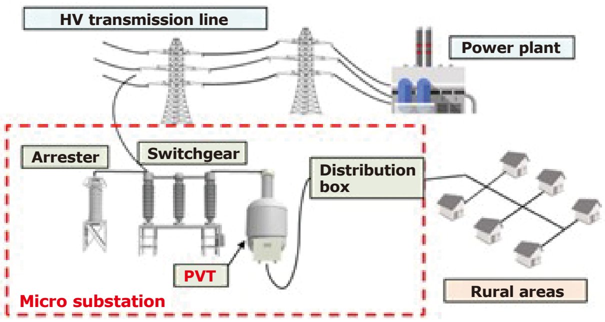


Fig. 1. Rendered image of supplying power from a micro substation

2-2 Features of micro substations

As a means of supplying power to an area with undeveloped distribution networks, a micro substation is more advantageous in terms of cost, space, and CO_2 emissions compared to power supply systems that rely on conventional substations or diesel generators. Table 1 provides a comparison of the characteristics of the different systems that can supply power to an area with undeveloped distribution networks.

(1) Low cost

A micro substation is advantageous in that its target equipment cost is about one-third or less than the equipment cost of a conventional substation.

The operating cost can be kept low because unlike diesel generators, the micro substation requires neither refueling nor frequent maintenance.

(2) Space saving

The micro substation features a simple system configuration, with its installation space being compact at 8 m by

Table 1. Comparison of characteristics of electricity supply systems for areas with undeveloped distribution networks

	Micro substation	Conventional substation	Diesel generator
Equipment cost	Medium	High	Low
Operating cost	Low	Low	High
Installation space	Small	Large	Small
CO_2 emissions†	192 t-CO_2/year		569 t-CO_2/year
Power output capacity	100 kVA	20 MVA	Several hundreds of kVA

† Comparison in terms of 100 kVA equipment
The systems were evaluated in terms of annual CO_2 emissions from supplying power at the maximum loading of 100 kW and average loading of 50 kW 24 h a day, 365 days a year.
† CO_2 emission intensity of power grids: 0.439 kg-CO2/kWh
(Source: Announced values of FY2020 CO_2 emissions performance [preliminary estimates] by the Electric Power Council for a Low Carbon Society, whose membership consists of 65 electric companies)
† CO_2 emission intensity of 100 kW-class diesel generators: 1.30 kg-CO_2/kWh
(Source: Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories)

10 m as compared with the minimum installation space of 50 m by 50 m of a common conventional 66 kV substation, making the provision of an installation space easy.

(3) Low environmental impact

The micro substation enables approximately 70% CO_2 emissions reduction as compared with a small diesel generator rated at approximately 100 kVA.

Considering that the micro substation can supply 100 kVA of output power, we determine it to be suitable for supplying power to small villages in areas where transmission lines are available but the distribution network is not sufficiently developed.

3. Basic Micro Substation System Design

3-1 Basic design of the micro substation system for demonstration testing

The system consists of simple electrical equipment connecting one 100 kVA PVT unit to 66 kV transmission lines (one phase) and supplies single-phase 240 V to consumers. The micro substation system, as with the conventional substation, ensures protection coordination of each device (molded case circuit breaker [MCCB], over-current relay [OCR], and the like) to ensure minimum impact on power grid operation and consumers (loads) in the event of an accident, whether on the PVT's primary side, secondary side, or load end.

3-2 Points to note when developing a basic system design

This demonstration test system was designed in compliance with the International Electrotechnical Commission (IEC) standards and the Indian Standard (IS) for electric power. Due to limited experience in complying with IS standards, Nissin Electric relied on the expertise of TATA Power-Delhi Distribution Limited (TATA Power-DDL) for this matter. Furthermore, some parts of the system follow the internal standards of TATA Power-DDL for the purposes of security measures.

In recent years, India has experienced extreme heat reaching 50°C. We adapted the system to such harsh climate conditions.

(1) Protection coordination

Protection coordination was established between the detection time of the protective relay on the transmission line end, the operation of the MCCB on the PVT's secondary side, and the circuit-breaking characteristics of the gas circuit breaker (GCB) and overcurrent (OC) relay.

(2) Security measures

A dual redundant structure was implemented as per TATA Power-DDL's request, installing a disconnect switch (DS) on both the primary and secondary sides of the GCB. This structure ensured system security measures with enhanced safety, such as for the maintenance of the GCB.

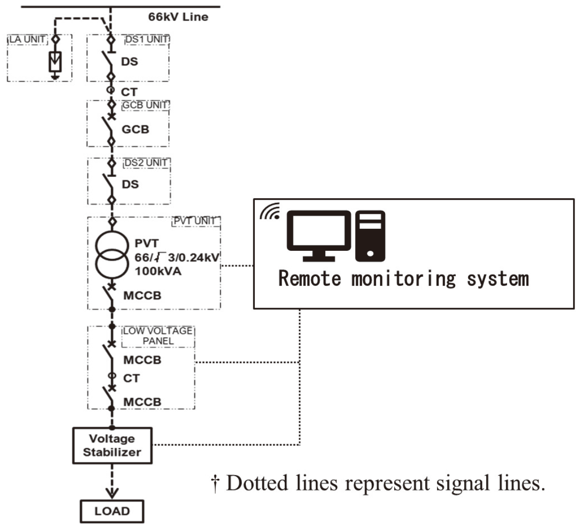
(3) Power quality measures

Unlike common voltage transformers, the PVT has no voltage adjustment tap. Therefore, a voltage stabilizer was installed on the load side as a countermeasure against voltage fluctuations.

(4) Remote monitoring system

The demonstration test system constantly measures the voltage, current, power, frequency, and other characteristics with a data logger and power quality analyzer. Each measuring device is networked, allowing for status monitoring and downloading of measurement data in Japan via the Internet. To ensure the security of the Internet environment, safe communications have been established by means of multi-factor authentication and transport layer security (TLS) encrypted communication.

Figure 2 presents a configuration diagram of the demonstration test system designed with the above in mind.



† Dotted lines represent signal lines.

Fig. 2. Configuration diagram of the demonstration test system

3-3 Equipment selection

(1) Development of the PVT for demonstration tests

The PVT is based on voltage transformer technology, which directly transforms HV to low voltage and measures the voltage. Thanks to the highly reliable insulation technology developed by Nissin Electric, this voltage transformer has been made larger in capacity to supply power up to 100 kVA.

The PVT is structured to house an iron core and coils in an aluminum casing and uses O-ring gaskets to maintain the airtightness of each gastight part.

Photo 1 shows the PVT developed for the demonstration test system. Continuous transposed conductors are used as the secondary coil wire of the PVT. Continuous transposed conductors are mostly used in large transformers. Winding continuous transposed conductors require high winding skills. Nissin Electric has winding technology that uses transposed conductors and leveraged this technology to make the PVT a high-capacity transformer.

(a) To increase the capacity of the PVT, the diameter of its secondary coil was increased. This was achieved by leveraging Nissin Electric's proprietary winding technology for large-diameter wire coils.

(b) The casing was designed to have cooling fins all over it for increased heat exchange efficiency. This design ensures that the PVT operates without any issues under the demanding air temperature condition in India (approximately 50°C).

(c) The secondary coil of the PVT uses a transposed conductor in order to reduce losses and improve efficiency by ensuring uniform current flows to reduce eddy currents.

Photo 1. PVT for demonstration tests (66 kVA, 100 kVA)

Table 2 shows a list of specifications for the PVT developed for the demonstration tests based on the above.

Table 2. Specifications for the PVT for demonstration tests

Transmission line voltage	66 kV
Rated primary voltage	66/√3 kV
Secondary voltage	240 V
Rated power	100 kVA
Efficiency	97.1% (at 25 kVA loading)
Frequency	50 Hz
Ambient temperature	−25–50°C
Outline dimensions	φ1,285 mm × H3,010 mm
Mass	3,500 kg

(2) Key devices other than PVT

The micro substation consists of the following key devices in addition to the PVT.

- LA (Lightning Arrester)
- DS (Disconnect Switch)
- GCB (Gas Circuit Breaker)
- Low Voltage Panel
- Voltage Stabilizer

For this demonstration test, all power receiving and transforming equipment, except for the PVT, was configured using devices available from local Indian manufacturers as requested by TATA Power-DDL. Manufacturers' standard products were selected except for the GCB. Regarding the GCB, three-phase circuit breakers are usually the mainstream, consequently, there were no manufacturers who carried single-phase circuit breakers. Therefore, we selected two GCB manufacturers with capabilities to provide satisfactory product quality. After careful negotiations with the manufacturers, we instructed them to construct single-phase circuit breakers, purposely built for this project.

4. Organizing a Demonstration Test in India

This demonstration test is being conducted as an international demonstration project of the New Energy and Industrial Technology Development Organization (NEDO). The project plan proceeded as follows: in fiscal 2024, we built an international demonstration project framework, and subsequently developed the overall system design, selected equipment specifications, and procured the equipment; in fiscal 2025, construction of the micro substation commenced; following the completion of construction, as well as the acquisition, analysis, and evaluation of the measured data, demonstration testing commenced.

In June 2025, the micro substation was constructed at a TATA Power-DDL-owned substation in the suburbs of Delhi, and an opening ceremony was held. Since the commencement of operation, the validity of the system has been verified by acquiring demonstration data through measurement and analyzing and evaluating the data.

4-1 Construction work

Foundation work started in April 2025 and equipment installation work was completed in June 2025, under the supervision of TATA Power-DDL.

At the construction site in Delhi in India, it was not possible to secure an adequate amount of construction work time due to intense heat reaching an air temperature of 50°C, so the construction was delayed. Subsequently, we had frequent meetings with the relevant local parties involved to closely review the construction schedule. In late May, Nissin Electric dispatched skilled hard-hatted workers to facilitate the construction work and make up for lost time in the work schedule. In June 2025, the construction of the equipment for the micro substation system for demonstration testing was completed. Photo 2 illustrates the completed demonstration test system.

Photo 2. Exterior of the demonstration test system

4-2 Opening ceremony

An opening ceremony was held on June 18, 2025, at TATA Power-DDL's Smart Grid Lab and at the micro substation construction site.

Following greetings by Nissin Electric and TATA Power-DDL, principal guests gave their greetings and inspected the micro substation.

5. Analysis and Evaluation of Demonstration Test Data

This demonstration test aims to verify that the PVT micro substation is capable of supplying electricity safely and stably to consumers. Accordingly, we measured continuous operation data of this demonstration test system and used the data to analyze and evaluate the electricity supplied.

1) Electricity supply status
2) Time residence rate within the specified supply voltage value of 240 V ± 6%: Reliability of supplied electricity
3) Status of supplied electricity: System efficiency

5-1 Status of supplied electricity

The demonstration test, in which operation commenced in June 2025, started by checking the operation of the system with a limited number of consumers (two households) in the initial phase so as to check the reliability of the system. Subsequently, as the system proved itself to provide a stable supply of electricity, operation with 15 consumer households started on September 17. This paper reports on the analysis results of measurement data acquired during five weeks from September 17 to October 21, 2025.

Figure 3 presents comparative analysis results comparing one week in late September and one week in mid-October with regard to load characteristics, focusing on electricity consumed by the consumers (supplied electricity) and air temperature. The loads were mostly lighting and air conditioning systems.

Similar electricity consumption trends were observed throughout one week (holidays and weekdays) in September. Electricity consumption peaks occurred characteristically not only during daylight hours (about 16:00) but also midnight hours (24:00). In contrast, in October, electricity consumption by consumers showed a levelling trend due to drops in air temperature, presenting similar trends throughout one week. It is presumed that the use of air conditioners became less frequent in that period.

The demonstration test system proved itself to have supplied electricity normally in response to load fluctuation even in a harsh environment with the air temperature reaching approximately 40°C.

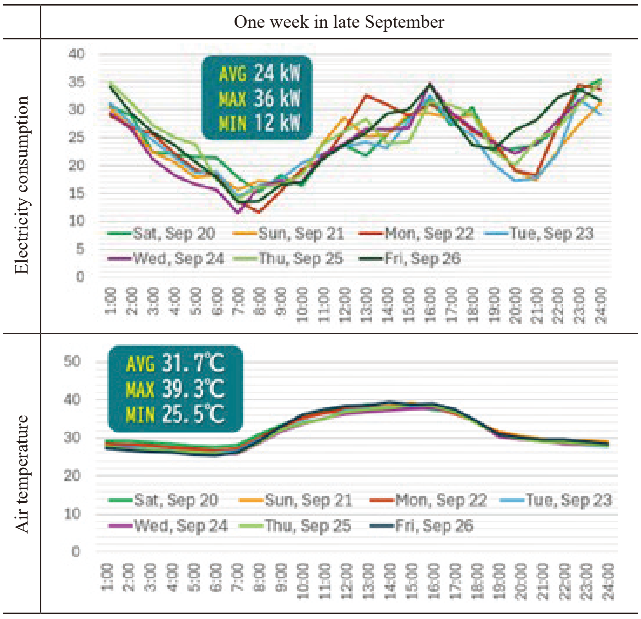


Fig. 3-1. Electricity consumption and air temperature characteristics for September

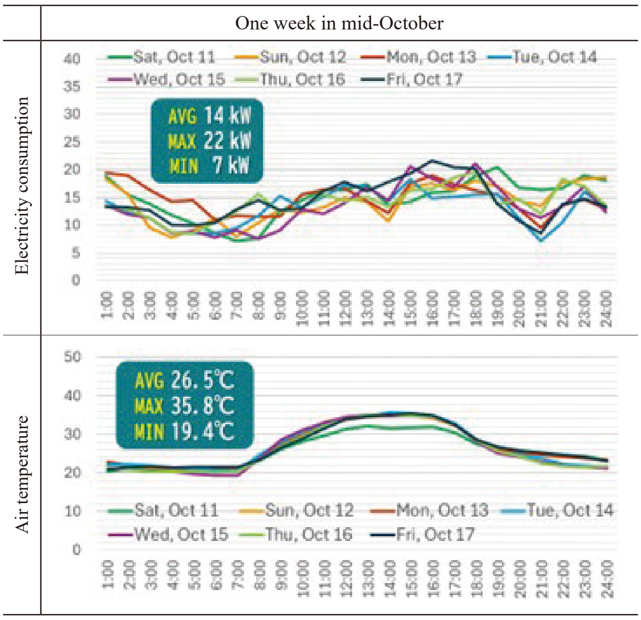


Fig. 3-2. Electricity consumption and air temperature characteristics for October

5-2 Time residence rate within the specified supply voltage value of 240 V ± 6%: Reliability of supplied electricity

In India, supply voltage to consumers (240 V) is required to stay in the range of specified values, or 240 V ± 6% (254.4 to 225.6 V). The demonstration test checks whether the operation of the micro substation fulfills this condition.

Since operation commenced in June 2025, the power grid (the primary side of the PVT) in India has experienced no outage, transmitting stable power all the time to the micro substation. However, the micro substation had to undergo a power outage due to scheduled work for about two hours on Friday, September 19 during the test period (from September 17 to October 21, 2025). Therefore, the data corresponding to this period of power outage due to work is excluded from analysis and evaluation.

Figure 4 illustrates staying rates measuring that the supply voltage stays within the specified range of 240 V ± 6% (254.4 to 225.6 V) at two measurement points on the PVT's secondary side and on the consumer end.

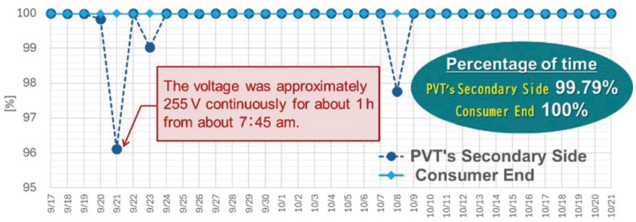


Fig. 4. Staying rate within the required voltage range of 240 V ± 6%

This system has a voltage stabilizer installed between the PVT's secondary side and consumer end. According to the results presented in Fig. 4, the staying rate was 99.79% with the voltage on the PVT's secondary side somewhat deviating from the required value of 240 V ± 6% (254.4 to 225.6 V). The voltage on the consumer end stayed within the required range owing to voltage stabilization. Consequently, Fig. 4 proves that electricity was supplied stably.

5-3 Status of supplied electricity: System efficiency

System efficiency is calculated based on PVT efficiency and power transmission efficiency. In addition, voltage stabilizer efficiency should be taken into consideration given that the system incorporates a voltage stabilizer. For this calculation, 97.1% (at 25 kVA loading) was chosen as PVT efficiency based on the results from the factory test report.

The efficiency of the demonstration test system was determined to be 90.1% based on measurement data. For reference, in India, aggregate technical and commercial (AT&C) losses occurring between power stations and consumers amounted to 17% in 2023, or an operating efficiency of 83%.[3] Compared to this indicator, the efficiency of the demonstration test system (90.1%) is high, therefore the demonstration system can be evaluated as being operated efficiently.

Note that this system incorporates a voltage stabilizer, the efficiency of which is 95% (according to the manufacturer's specifications). Without this voltage stabilizer, the system efficiency would increase from 90.1% to 94.8%, enabling the system to operate more efficiently and be installed at a lower cost. For this reason, we plan on highlighting the need for the voltage stabilizer to distribution operators.

5-4 Evaluation results

Since the commencement of operation, the power grid (the primary side of the PVT) in India operated within the standard voltage range of 66 kV ± 10%, without any known outage on the power grid side.

This demonstration test has proven that it is possible to supply safe and stable power directly from HV transmission lines to low-voltage consumers via a PVT micro substation.

6. Conclusion

This paper described demonstration testing of a micro substation featuring a PVT in India, which started in June 2025.

We plan on carrying on further demonstration tests to deepen our understanding of the micro substation operation. In addition, going forward, we intend to strive to popularize and roll out micro substations globally with the aim of supplying electricity globally to areas with undeveloped distribution networks.

Technical Terms

*1 Micro substation: A substation designed to directly obtain approximately 10 kVA to 100 kVA of low-voltage power from HV transmission lines of 66 kV or higher, using a PVT that has been scaled up in capacity for power supply by applying transformer technology originally used for voltage measurement.

*2 Power voltage transformer (PVT): An instrument transformer that has been scaled up in capacity to enable direct supply of electric power by transforming high voltage (HV) directly to low voltage (LV), by applying transformer technology normally employed to step down HV to LV for measurement purposes.

*3 High voltage (HV): High voltage is defined as 35 kV (35,000 V) to 230 kV (230,000 V); low voltage is defined as not higher than 1,000 V.

*4 Voltage transformer: A device used to transform high voltage to low voltage for the purpose of measuring high AC voltage.

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Contributors

The lead author is indicated by an asterisk (*).

K. OKA*
• Chief, Nissin Electric Co., Ltd.

Y. TAKAHASHI
• Nissin Electric Co., Ltd.

N. MAKI
• Nissin Electric Co., Ltd.

M. MURAI
• Group Manager, Nissin Electric Co., Ltd.

G. HIRAMOTO
• Group Manager, Nissin Electric Co., Ltd.

S. MIZUNO
• Senior Assistant General Manager, Nissin Electric Co., Ltd.