# Technical Application of Power Electronics to Small-Scale Hydropower Generation Systems

Toshitake Masuko,
Yohei Koishikawa,
Jun Mitsuta

Keywords Small-scale hydropower, Variable speed, Autonomous operation, FRT

**Abstract**

**We developed a small-scale hydropower generation system using power electronics technology. By applying power electronics technology, variable speed control enables efficient operation in response to changes in flow conditions such as the head. By adopting a full converter system that utilizes a general industrial inverter, there is no need for incidental equipment such as brushes, making maintenance easier.**

**It complies with grid interconnection regulations, including islanding detection and Fault Ride Through (FRT). It also has features, such as being able to make an isolated operation to feed the designated loads during a power outage, and can be used as an emergency power source.**

**This system is suitable for situations where conventional power generation systems cannot operate efficiently, such as when generating electricity by maintaining and releasing water from unused dams, or when it is desired to utilize hydropower generation as an emergency power source.**

## 1 Preface

As efforts toward carbon neutrality progress, hydropower is an important power source for making renewable energy as the main power source. After the Feed-in Tariff (FIT) system was implemented, repowering and the construction of small-scale hydropower plants at undeveloped sites have been carried out. Power generation at unused dams is being considered, and generation facility that utilizes water discharge for maintenance is being introduced.

The problem with such dams, however, is that they cannot be operated efficiently with regular water turbine generators due to fluctuating dam water levels throughout the year. Additionally, there is a growing desire to utilize hydropower as a standalone power source during natural disasters. This paper introduces a small-scale hydropower generation system that uses power electronics technology to operate efficiently and makes an isolated operation during power outages.

## 2 Power Electronics System for Small-Scale Hydropower Generation

### 2.1 Full Converter System

Fig. 1 shows the configuration of a full converter system for small-scale hydropower generation, and Fig. 2 shows the external appearance and panel configuration. A three-phase Pulse Width Modulation (PWM) voltage inverter converts the generator output to DC, then converts it back to AC and connects it to the grid. With this configuration, the generator side unit and grid side unit can do the control almost independently. By controlling the three-phase AC with an inverter, the generator does not require an excitation circuit, improving maintainability.

Furthermore, the main circuit part of the converter is the same as that of general industrial inverters. The parts used are, therefore, easily available and maintainability is high. The equipment configuration is also the same as a general industrial inverter panel.

### 2.2 Advantages of Full Converter System

By adopting a full converter system, when connected to the grid, the generator controls the gener-

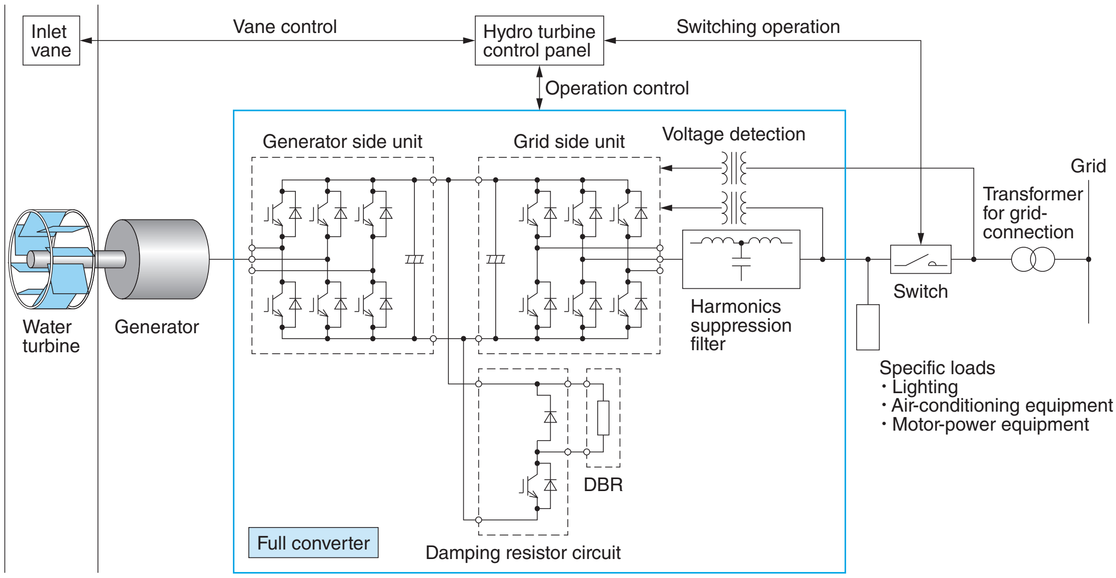
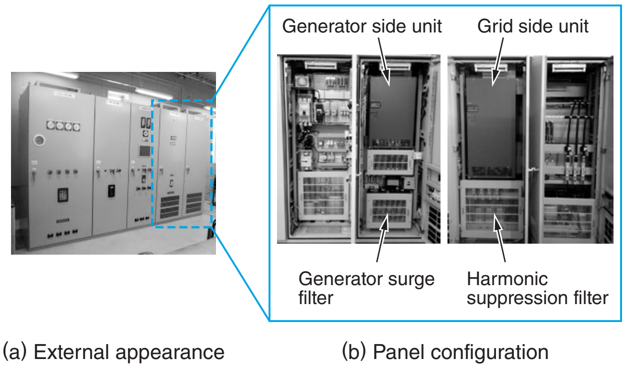



**Fig. 1** Configuration of Full Converter System

A system configuration outline is shown.




(a) External appearance (b) Panel configuration

**Fig. 2** External Appearance and Panel Configuration

An external appearance and panel inside configuration are shown.

ator to provide highly efficient power generation by the control of the generator side unit through its variable speed control. In the event of a power outage (disconnected from the grid), power is supplied to the load of the on-site equipment through the isolated operation of the generator by the control of the grid side unit. It also requires no brushes and is easy to maintain.

## 3 Control by Generator-Side Unit

We will introduce the distinctive technologies of small-scale hydropower by the control of the generator side unit and the grid side unit. Conventional hydro turbines and other generators generally have a fixed speed, but variable speed control is achieved by using power electronics to vary the frequency and voltage. This improves power generation efficiency during variable head operation. Additionally, there is no need for excitation circuits such as induction generators or permanent magnet generators, allowing the use of inexpensive and robust generators. Furthermore, since it can be controlled without attaching a precise speed sensor, it also leads to improved maintainability.

### 3.1 Variable Speed Control Method

This section explains how variable speed control improves power generation efficiency. The power generated by a hydro turbine depends on the head and flow rate, and for a typical hydro turbine, the relationship between the rotational speed, head, and efficiency is as shown in **Fig. 3**.

In dams and rivers, the head and flow rate fluctuate depending on the weather and season, and fixed speed control does not necessarily result in operation at the maximum efficiency point. By using power electronics technology to variably control the rotational speed of the hydro turbine, it is possible to generate electricity with maximum efficiency at the current head.

**Fig. 4** shows specific verification examples: (a) is the verification result when the flow rate is constant and the head is varied, and (b) is the verification result when the head is constant and the flow rate is varied. We confirmed that the power generation output is improved by variable speed.

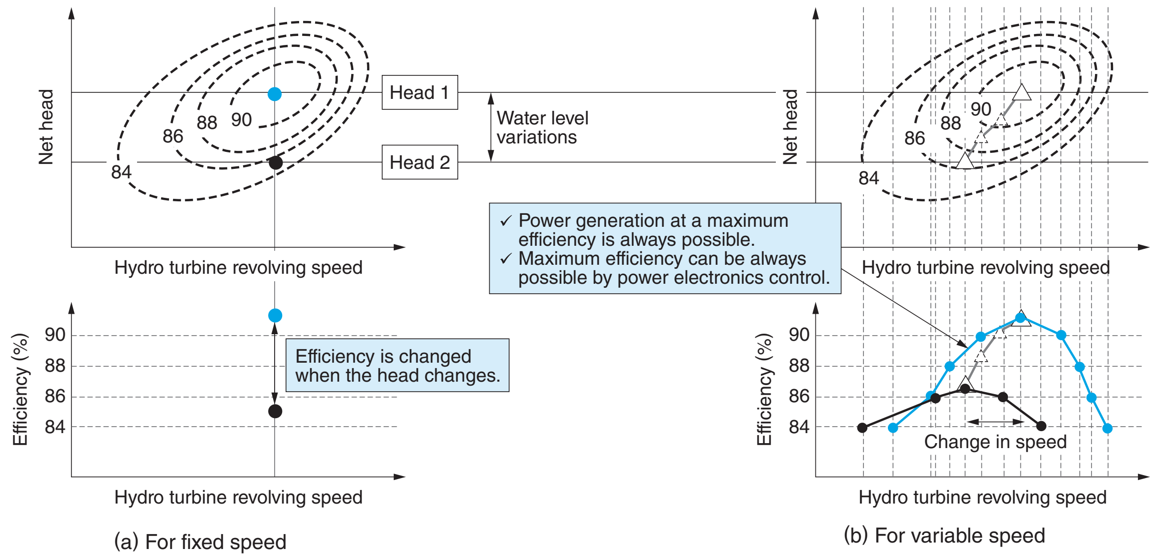
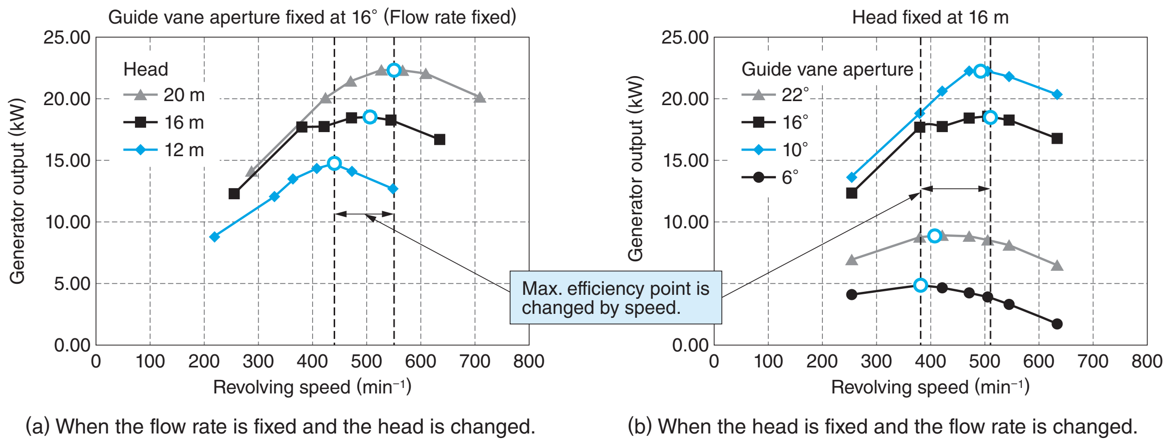



**Fig. 3** **Relationship between Water Head, Flow Rate and Efficiency Using Variable Speed Control Method**

The variable speed control method is shown.




| Head | Fixed speed | | Variable speed | | Output increment |
|---|---|---|---|---|---|
| | Speed | Output | Speed | Output | |
| 20 m | 429 | 20.0 | 527 | 22.2 | 11.0% |
| 16 m | 429 | 18.0 | 507 | 18.5 | 2.8% |
| 12 m | 429 | 14.8 | 429 | 14.8 | 0.0% |

✓ Even when the head is changed, output can be increased by variable speed control.

✓ Similarly as when the flow rate is changed.

**Fig. 4** **Verification Examples of Variable Speed Control**

An example of variable speed control verification is shown.

## 3.2 Sensorless Control

Sensorless control operates while estimating the rotational speed and phase by calculating a model of the rotating machine using the inverter's own current and voltage. This eliminates the need for a rotational speed sensor. Particularly for submersible hydro turbines, where the turbine is inserted into a waterway, sensorless technology has a significant effect on reducing wiring. **Fig. 5** shows a submersible hydro turbine.

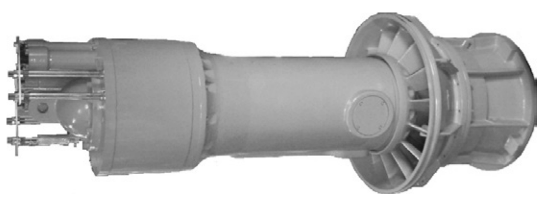


**Fig. 5** **Submersible Hydro Turbine**

An example of a sensorless control object (hydro turbine by EAML Engineering CO., LTD.) is shown.

## 4 Control by Power System Side Unit

For the high-quality power source designed in accordance with the standard of the grid-connection and techniques for harmonics restriction by using built-in LC filters, the following features are available:

(1) Conformance to the standards of grid-connection such as functions of detection of islanding operation and Fault Ride Through (FRT)

(2) Adoption of the isolated operation function enabling the utilization as an emergency power supply in the case of a power outage or disaster

This system has features so that it can be utilized as an emergency power supply in the case of a power outage or disasters irrespective of day or night, so long as there is a water flow. Further, it is applicable to a blackout start because no exciter control is required, provided that the generator is of the permanent-magnet rotor type.

### 4.1 Isolated Operation System

Fig. 6 shows the isolated operation system. When a power outage occurs, such a condition is sensed to trip the converter output switch and the system is switched over to the isolated operation mode. During isolated operation, maximum-efficiency-based speed-variable control is changed over to DC voltage constant torque control in the control of the generator side unit and generator torque is controlled so that the DC voltage is not lowered by the effect of load current. On the grid side unit, DC voltage constant synchronized control is changed over to fixed-voltage and fixed-frequency output control.

If the load power is small during an isolated operation, excess power can be absorbed with the use of a damping resistor to prevent over-speed running of the water turbine.

### 4.2 Load Follow-up Control During Isolated Operation

As introduced above, power electronics technology can make a variable control of hydro turbine speed and torque. As a result, this type of control can follow up power consumption of the load even during isolated operation.

Fig. 7 shows load follow-up control during the isolated operation. When the load is increased or an

| Mode | Control by generator side unit | Control by grid side unit |
|---|---|---|
| During grid-connection | Max. efficiency variable speed control | DC voltage fixed and source synchronized control |
| ⇕ Automatic changeover ※In the case of changeover to isolated mode, a short-time power outage can occur. | | |
| During autonomous operation | DC voltage fixed torque control | Voltage output control |

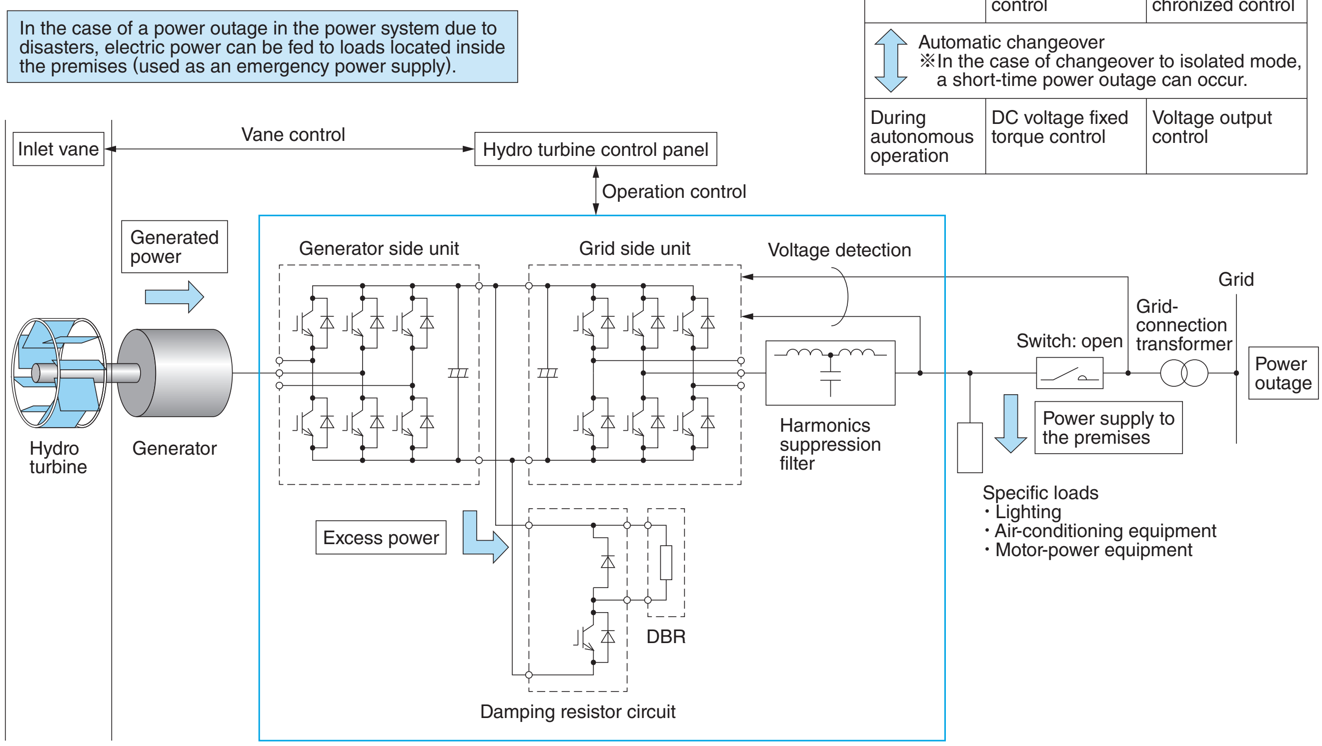



**Fig. 6 Isolated Operation System**

An outlined scheme of isolated operation control is shown.

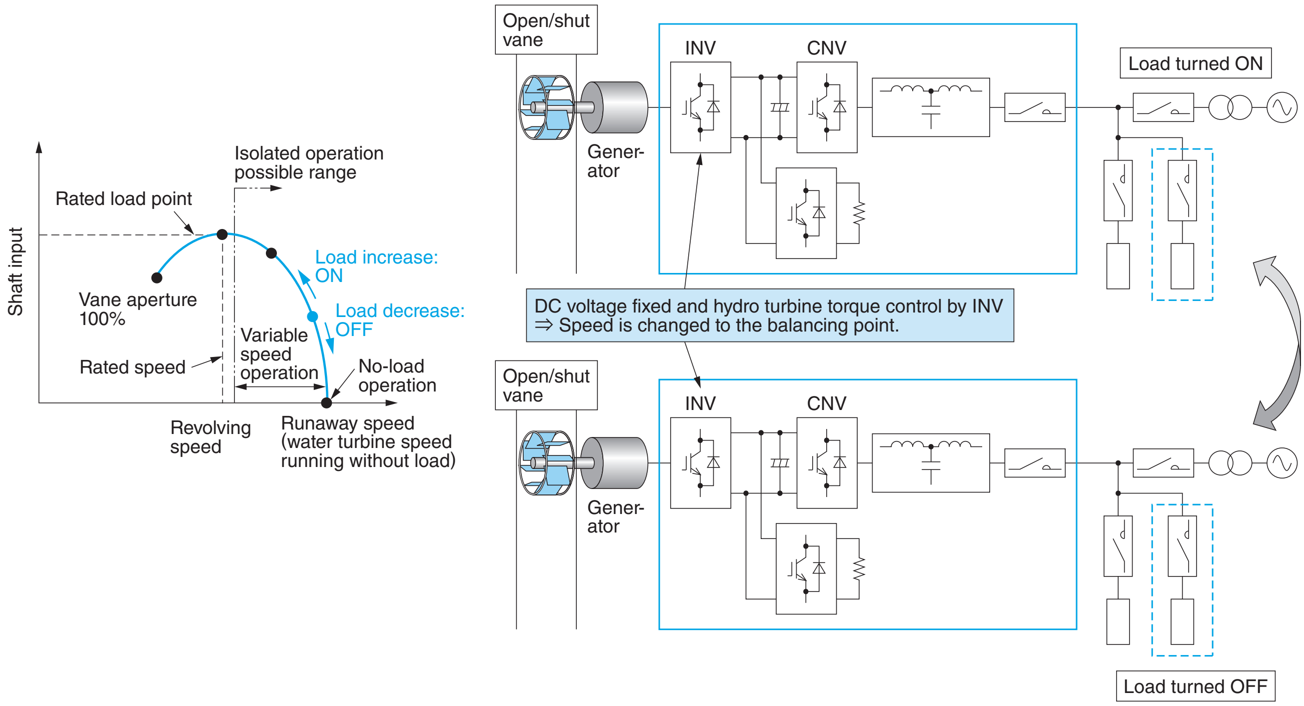



**Fig. 7** **Load Follow-Up Control during Isolated Operation**

Load follow-up control for isolated operation is shown.

additional load is applied, the speed is reduced by increasing the torque.

Conversely, when the load is reduced or released, the speed increases. In such a manner of control actions, as long as the power is suppliable, it can keep up with the changing load.

## 5 Postscript

Hydropower generation is a power source that generates the least amount of $CO_2$ among renewable energy resources, and it is also a distributed energy resource that is deeply rooted in the local community. To effectively utilize this important energy resource, we have developed a small-scale hydropower generation system using power electronics technology.

We will continue to develop hydropower generation products while incorporating new technologies.

・All product and company names mentioned in this paper are the trademarks and/or service marks of their respective owners.