Grid Connectable NTN Micro Hydro Turbine

1. Introduction

The energy issue is a global challenge that we have to deal with to achieve a sustainable society. Some of the key initiatives include reduction of greenhouse gas emissions related to recent climate change, energy saving for phasing out fossil fuel dependency, and diversifying energy sources by promoting use of renewable energy. Fig. 1 shows the actual power mix before the Great East Japan Earthquake and the prediction for FY2030. Renewable energy, in particular, is assumed to more than double from the actual ratio before the Great East Japan Earthquake, indicating high expectations.

Demand of renewable energy such as hydroelectric power generation is increasing rapidly from rise of global warming and the interest to the energy mix. NTN already commercialized the NTN Micro hydro Turbine which is used in existing agricultural canal and industrial canal and makes electric power available in the place where the no power system exists. NTN develops Grid Connectable NTN Micro hydro Turbine. This paper introduces the features and the structure of the developed products.

Securing the emergency power supply in case of natural disasters is also a great challenge. Although standby generators are being installed for emergency power sources, storage of fuel is another challenge. Renewable energy does not require storage of fuel and can be used as an emergency power source. NTN has productized a Green Power Station, which stores power from photovoltaic power generation and wind power generation into batteries and is used for lighting at night or as an emergency power source.

Hydraulic power generation is a stable power source with little variance compared to photovoltaic or wind power generation. NTN has developed and productized the "NTN Micro Hydro Turbine" which uses the energy of running water in waterways. NTN Micro Hydro Turbine is an independent power source which assumes private consumption by storing generated power in batteries for supply in the areas without good power infrastructure or as an emergency power source in case of disasters.

On the other hand, feed-in tariffs (FIT) started in July 2012 to promote renewable energy in Japan. FIT is a program to require power companies to purchase power generated by renewable energy at a fixed price. Introduction of this program facilitates recovery of capital investment; therefore, installed bases of photovoltaic power generation is significantly growing.

Fig. 1 The power supply construction in FY2030

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*Engineering Dept. Green Energy Products Division
NTN’s own market research revealed that there was strong demand for hydraulic power generation of the grid connectable type, so that the generated power can be sold, taking advantage of FIT. In addition, since the purchase price for hydraulic power generation of less than 200 kW is more profitable than 200 kW or more, as shown in Table 1, adoption of hydraulic power generation of less than 200 kW will be likely to grow.

In this article, we describe the structure and features of “Grid Connectable NTN Micro Hydro Turbine” that NTN has developed which allows sale of generated power.

<table>
<thead>
<tr>
<th>Table. 1 FIT price of hydro turbine</th>
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<td>Purchase period</td>
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<tr>
<td>1,000 kW or more and less than 5,000kW</td>
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<tr>
<td>200kW or more and less than 1,000kW</td>
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<tr>
<td>Less than 200kW</td>
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<td>116 years</td>
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2. Grid connection

Grid connection means that power generation facilities such as photovoltaic power generation and hydraulic power generation are connected to power transmission lines or power distribution lines of utility companies, as shown in Fig. 2. By connecting power generation facilities to the grid, the generated power can be sold to the utility companies.

3. Structure of Grid Connectable NTN Micro Hydro Turbine

Fig. 3. shows the outer view of NTN micro hydro turbine, Table 2 shows the specification and Fig. 4 shows the configuration of Grid Connectable NTN Micro Hydro Turbine.

The AC power generated by NTN micro hydro turbine is converted to DC power by the controller and input to the power conditioner. The power conditioner is a device to convert the DC power to AC power and transmit it to the grid. The controller and the power conditioner are collectively called the grid connectable system, which enables power generated by the NTN micro hydro turbine to be efficiently transmitted to the grid and sold to the utility company.

<table>
<thead>
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<th>Table. 2 Specification of NTN Micro Hydro Turbine</th>
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<td>Hydro turbine blade diameter mm</td>
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<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>600</td>
</tr>
<tr>
<td>900</td>
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<td>1,300</td>
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Fig. 4 System configuration of Grid Connectable NTN Micro Hydro Turbine
4. Functions of the components of the grid connectable system

(1) Controller
The controller consists of rectifying circuitry which rectifies the power generated by the generator and control circuitry which controls the Grid Connectable NTN Micro Hydro Turbine. The controller has the following functions:
1) Converts (rectifies) the AC power generated by the generator to DC power and inputs it to the power conditioner.
2) Monitors the generated power and rotational speed of the generator.
3) Controls the rotational speed of the hydro turbine blades in order to push out foreign objects entangled in the blades.

(2) Power conditioner
The power conditioner is a device to convert the DC power converted by the controller to AC power, which is transmittable to the grid, and transmit it to the grid. In the grid connectable system of "Grid Connectable NTN Micro Hydro Turbine," the maximum power point tracking (MPPT) is adopted for the control of maximizing power generation.

5. Power generation control of Grid Connectable NTN Micro Hydro Turbine

MPPT is a control to automatically maximize power generation.

By applying MPPT to power generation control for hydraulic power generation, the load to the generator is changed to control the rotational speed of the turbine blades, while measuring generated power, for the speed to obtain the maximum power generation. The Grid Connectable NTN Micro Hydro Turbine has models for 0.4 kW, 1 kW and 2 kW of power generation and the standard implementation of MPPT for systems with less than 2 kW power generation is the first in the industry. MPPT implementation in the Grid Connectable NTN Micro Hydro Turbine has the following benefits:

- Eliminates the need for measuring the width, water level, and flow rate of the waterway to which the system is to be installed and adjusting the controller to the result, achieving a significant reduction in installation time and cost.
- Enables maximization of power generation, even when the water level or flow rate changes in the waterway.

The following is the control process of MPPT (Fig. 5):
(1) Reduce the rotational speed of the turbine blades from N1 to N2 to increase the power output from P1 to P2.
(2) Reduce the rotational speed of the turbine blades from N2 to N3 to increase the power output from P2 to P3.
(3) When the rotational speed of the turbine blades decreases from N3 to N4, power output changes from P3 to P4.
(4) As the power output decreases to P4, the rotational speed is increased back to N3.
(5) When the rotational speed of the turbine blades increases from N3 to N2, power output changes from P3 to P2.
(6) As the power output decreases to P2, the rotational speed is decreased back to N3.

By repeating this process, generated power is maximized.

However, when MPPT was applied to hydraulic power generation, there were cases where the maximum power generation could not be attained by the following:

When the flow rate and water level of the waterway changed abruptly in a short time and deviated from the maximum power point of MPPT, the control could not follow the change and the load to the generator continued to increase causing a shortage of turbine blade torque driven by the water flow and reduction of turbine blade rotational speed. This phenomenon occurs when, in Fig. 6 "Rotation speed of blades vs. torque characteristic diagram," the operating condition, which is usually at point (1), moves to the stall region such as point (2), causing reduction of rotational speed and torque of turbine blades, resulting in lower power generation.
The Grid Connectable NTN Micro Hydro Turbine compares and controls the turbine blade rotational speed and generated power at all times so that maximum power is attainable and the operating conditions never move into the stall region. The problem has been resolved by incorporating control to detect the deviation of the operating point and drive the MPPT to return to the maximum power point, even when the conditions move into the stall region.

Table 3 Test condition

<table>
<thead>
<tr>
<th>Item</th>
<th>Condition</th>
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<tbody>
<tr>
<td>Hydro turbine blade diameter</td>
<td>Ø 900</td>
</tr>
<tr>
<td>Water depth</td>
<td>670 mm</td>
</tr>
<tr>
<td>Flow rate in the demonstration test</td>
<td>2.0 m/s</td>
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*Fig. 6 Rotation speed of propeller vs torque characteristic diagram*

6. Demonstration test in the actual waterway

The demonstration test of the developed grid connectable system was conducted to evaluate performance. The configuration of the demonstration test is shown in Fig. 7 and the test condition is shown in Table 3. The demonstration test verified the tracking performance of the maximum power generation by MPPT of power conditioner. The waterway used for the demonstration test did not have enough water and a portion of the turbine blades was out of water.

First, the maximum power generation of the waterway under the demonstration test was verified by connecting the electronic load to the controller output, as shown in Fig. 8 (a), changing the generated voltage (proportional to the rotational speed of the turbine blades) and measuring the generated power. The results are shown in Fig. 9. The maximum generated power was 749 W.

Next, the power conditioner was connected, as shown in Fig. 8 (b) for the measurement. In this demonstration test, simulated power supply load was used to simulate the condition of grid connection.

Fig. 10 shows the results of the generated power. The generated power was 738 W on average, which means it has tracked the maximum power generation well.

![Grid Connectable NTN Micro Hydro Turbine](image)

![Fig. 7 Field test](image)

![Fig. 6 Rotation speed of propeller vs torque characteristic diagram](image)

![Fig. 8 Test lig layout of field test](image)

![Fig. 9 Result of field test](image)
7. Mechanism for easy operation "Easy Lifter"

When waterways are swollen by heavy rain from typhoons, etc, driftwood and debris may damage the hydro turbines. This should be avoided. If turbine blades can be lifted above water level, they can be more safely operated. NTN micro hydro turbine can be equipped with a mechanism, "Easy Lifter," to temporarily lift the turbine blades from the water in emergency.

In addition, this mechanism can also be used to safely and easily lift the blades without requiring heavy machinery such as cranes for periodic maintenance, allowing time and cost reduction for maintenance and inspection tasks. Fig. 11 shows the condition of normal operation and Fig. 12 shows how the blades are lifted up.

There are two ways for operating "Easy Lifter." Fig. 13 shows the lever type, where the turbine connected to the rotational shaft is manually operated by a lever pivoting at the NTN bearing unit, and Fig. 14 shows the worm gear type where electric motors can be mounted.

8. Conclusion

In this article, we have described the functions and features of "Grid Connectable NTN Micro Hydro Turbine" which allows the sale of electric power generated by NTN micro turbine, configuration and performance of the controller and power conditioner of NTN’s highly efficient and proprietary grid connectable system, and "Easy Lifter", which allows temporary lifting of the turbine blades from the water.

The market for hydraulic power generation using agricultural waterways, etc. is expected to grow with high demand for hydraulic power generation system with shorter recovery of capital investment and ease of operation. We will continue to work toward higher efficiency and respond to the needs for broader adoption of micro hydro turbines.

NTN is also working on fulfilling related products using natural energy, including photovoltaic and wind power generation for diversification of energy sources and achievement of a sustainable society.

For example, the demand and application area are expanding for NTN Hybrid Street Light 4), which was...
launched in 2016. NTN Hybrid Street Light has been adopted, as an independent power source and structure for the application “Disaster Relief Map,” the largest disaster rescue/prevention map in Japan developed by Osaka University and “Mimamori Robokun III,” Wi-Fi communication infrastructure equipped with a monitoring camera developed by the “National Activity Support Network for Local Municipalities,” a non-profit organization 5). “Mimamori Robokun III” is equipped with a monitoring camera and Wi-Fi equipment as a standard, as well as a LED light, and requires stable power supply even in an environment not favorable for wind or daylight conditions. Therefore, a higher power capacity version of the hybrid street light was newly introduced at the Green Power Station.

We will continue proposing locally produced and consumed energy through development and marketing of products that use natural energy in order to achieve a low-carbon society. In addition, we will contribute to the safety and security of local communities by demand stimulation at the local governments and local community associations.

References
1) Ministry of Economy, Trade and Industry: Long-term Energy Supply and Demand Outlook and related materials