Research article

Micro Hydroelectricity Using Irrigation Ponds for Better Water Management

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Received 22 January 2015 Accepted 15 July 2015 (*Corresponding Author)

Abstract This paper discusses estimates of hydroelectricity potential using irrigation ponds in mountainous areas. Hydroelectric power output is calculated from hydrological observations such as discharge from the ponds and water level at two irrigation ponds. Although these ponds have almost the same water storage capacity, water discharge patterns differ due to differences in the command areas. Results show that water management influences the pattern of hydroelectric power generation. The use of electricity is also important to consider since irrigation ponds in mountainous areas are distant from villages, which have no electricity infrastructure. In most cases, the irrigation ponds in mountainous areas are difficult to access. In addition, most of the water managers are aging and are having difficulty maintaining irrigation ponds and its water management. Therefore, using hydroelectric power to support the operation and maintenance of irrigation ponds would be one of the best ways to use the hydroelectric power generated at irrigation ponds. Finally, a field experiment of a micro-hydroelectricity system is conducted at an irrigation pond and the pond monitoring system is installed.

Keywords renewable energy, siphon intake, automatic control, monitoring system

INTRODUCTION

Irrigation ponds are used as supplemental irrigation for paddy rice fields in Japan. Recently, the generation of micro hydroelectricity using irrigation facilities as a form of renewable energy has received much attention due to encouragement by the Japanese government and the significant price increases in electric power. Irrigation ponds, especially those located in mountainous areas, can easily generate the gravitational drop, which is necessary for hydroelectricity generation and gives advantage to ponds in these areas more than the ones in flat areas.

Lots of investigations have been conducted by the government and local governments so the governments can estimate hydroelectricity potential in mountainous areas in Japan. However, most of them were calculated only by using topographic information and rainfall data without considering actual water management. Ueda et al. (2013) have reviewed small-scale hydropower generation using irrigation water in Japan. Ueda et al. (2015) had conducted a scenario analysis to propose a water management scheme to balance two objectives, irrigation and hydropower. There is no research on hydropower generation using small irrigation ponds, as there are many in mountainous areas especially in western part of Japan.

Therefore, this paper discussed and estimated hydroelectricity potential using Nanatani pond and Matsutani irrigation ponds in Tottori, Japan and the use of electricity by considering current water management practices. Moreover, field experiment of hydroelectricity was conducted at Yanaka pond in Tottori.

METHODOLOGY

Irrigation ponds are categorized into two groups, including ponds in mountainous areas and in flat areas. In this paper, siphon intake is assumed to estimate the hydroelectricity potential using irrigation ponds in mountainous areas. There are advantages of employing siphon intake, such as preventing dust entering, making use of water head for hydroelectricity, reducing initial investment for hydroelectricity, and easier water management than conventional practices.

Study Areas

Two irrigation ponds, Nanatani and Matsutani, were selected in this study. Both of them are located in mountainous areas of Tottori Prefecture, Japan. Storage capacities of the two ponds are more than 200,000 m^3 and the height of both ponds are over 12 m. Considering more than 50% of irrigation ponds in Tottori, the ponds have less than 10,000 m^3 of water storage capacity, which are relatively big ponds. Besides, there were significant differences in beneficiary areas and catchment areas. Catchment areas of Nanatani pond were about half of the Matsutani's one while beneficiary areas of Nanatani were more than 3 times of the Matsutani's one. Water was collected from runoff of each catchment area only and there was no water supply from river water. General descriptions of the selected irrigation ponds are summarized in Table 1.

Table 1 General information about observed ponds

Name of Pond	Nanatani	Matsutani
Storage capacity (10,000 m^3)	210.0	259.2
Dam height (m)	12.0	16.5
Catchment area (ha)	30.0	62.0
Beneficiary area (ha)	44.5	13.0
Water resource	Runoff	Runoff

Hydrological Observation and Estimation of Hydroelectricity

Siphon intake was assumed in this study instead of conventional operation. The opening and closing bulbs on inclined inlet pipe were employed to make use of advantages of siphon for hydroelectricity such as avoiding trash intake, easier operation of open and close gate, and getting water head and lower cost. The outlines of hydroelectric system are illustrated in Fig. 1.

Also, hydroelectric power output (kW) is calculated as following Eq. 1.

$$P = \rho g H_e \, Q \, \eta \qquad (1)$$

Where, P is electric output (kW), ρ is density of water (1,000kg/m^3), g is gravity acceleration (9.8 m/s^2), He is effective head (m), Q is discharge (m^3/s), η is efficiency (0.601).

Water levels of irrigation ponds and canals were monitored in every 10 minutes during irrigation season in 2010 and 2011. A level survey was conducted to determine the head and for hydrological observations such as discharge from the ponds and water level. Height-volume curves of irrigations ponds and height- discharge curves of irrigation canals were also prepared for the two ponds based on the field survey.

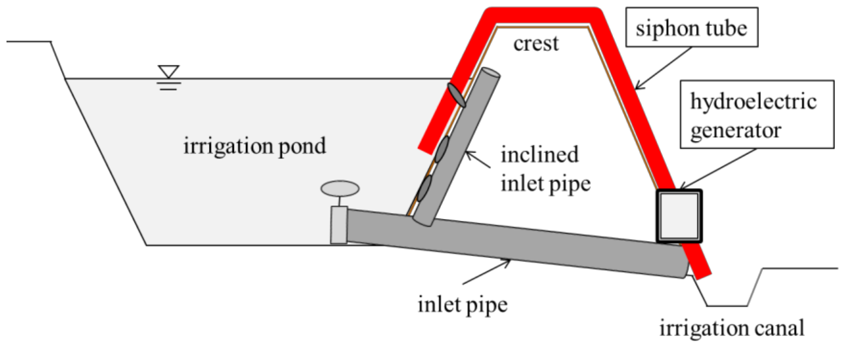


Fig. 1 Outlines of hydroelectric system

Field Experiment

Field experiment of siphon intake and hydroelectricity was conducted at Yanaka pond in Tottori during non-irrigation period. Usage of generated electricity was also demonstrated such as installing electric bulb for easier water management and or monitoring system to inform water managers for the water level of the ponds.

RESULTS AND DISCUSSION

Estimated Hydroelectricity

Fig. 2 (a) shows the estimated power output of Nanatani pond in 2010. Irrigation period is 106 days from May 30 to September 12. Water discharge varied daily because water managers conventionally opened the gate at 6 a.m. and close at 6 p.m. Water manager also adjusted the discharge according to rainfall events. If it rained at 6 a.m., the water manager would not discharge water. If it rained at daytime, the manager would go to the pond to decrease and/or stop discharge.

Fig. 2 (b) shows estimated power output of Matsutani pond in 2010. Irrigation period is 104 days from June 1 to September 12. Compared with Natanani pond, Water level and discharge at Matsutani pond were more stable. Irrigation water was released 24 hours and water discharge was adjusted every 3-4 days at Matsutani pond.

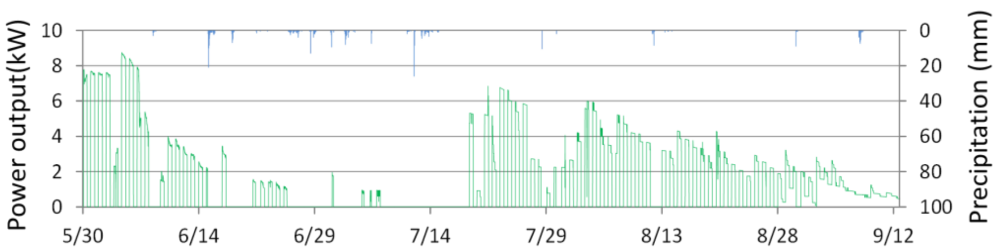
Table 2 Summary of the estimated output, 2011

Pond	Nanatani	Matsutani
Gross generation (kWh)	1,821.0	3,443.0
Total discharge (10^3 m^3)	199.7	265.2
Maximum output (kW)	5.0	3.6
Average output (kW)	1.7	1.3
Monitoring time (h)	2,538.0	2,610.0
Discharge time (h)	1,080.0	2,610.0
Generating time (h)	1,080.0	2,610.0
CO_2 conversion ($kgCO_2$)	1,011.0	1,911.0
Oil conversion (L)	462.6	874.5

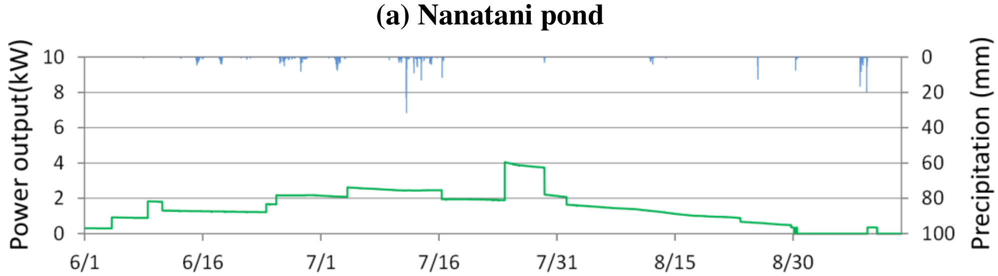
Table 2 shows the results of estimated hydroelectricity of two ponds for the year of 2011. The maximum electric power output and electric power were 4.92 kW and 1,420 kWh at Nanatani pond and 3.57 kW and 3,000 kWh at Matsutani pond. Although these ponds had almost the same water storage capacity, water discharge patterns differed due to differences in the command areas. Nanatani pond had larger command area than Matsutani pond; therefore, strict water management was practiced at Nanatani pond. The water manager at Nanatani pond usually opened the gate at 6 a.m. and closed at 6 p.m., and the water gate was closed when it rained. On the other hands, the water manager at Matsutani pond usually kept the gate opened and the discharge was controlled twice a week during the irrigation period. Therefore, the water level of the pond decreased continuously at Matsutani pond while the water level of the pond slowly decreased at Nanatani pond due to its strict water management. As a result, hydroelectric power was continuously generated at Matsutani pond compared with Nanatani pond. It shows that water management influences the pattern of hydroelectric power generation.

Result of Field Experiment

A field experiment of a micro-hydroelectricity system was conducted at Yanaka irrigation pond in Tottori, Japan. Electricity output was also continuously monitored in two weeks to examine the stability of output. Fig. 3 shows the results of field experiment. Stable output about 1.2 kW was observed during the first 10 days from February 1 to 10. Then the output decreased according to the lowering of water level in the pond.

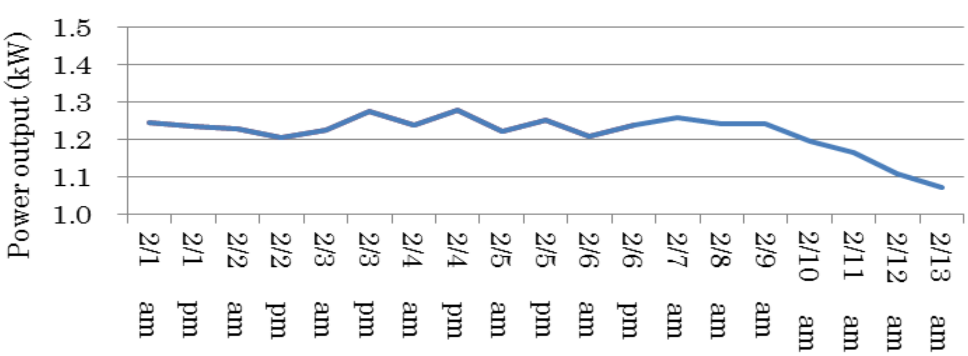


(a) Nanatani pond



(b) Matsutani pond

Fig. 2 Estimated power output at observed ponds, 2010 (Kusaka et al., 2011)



(Discharge: 52 L/s, Generating efficiency: 45~50%)

Fig. 3 Power output of the field experiment

Usage of Generated Electricity

The usageof the electricity was also important since irrigation ponds in mountainous areas were distant from villages and had no electricity infrastructure. Consequently, the electricity generated at ponds could not be readily used by villagers and farmers. In most cases, it was observed that the farm ponds in mountainous areas were difficult to access. In addition, most of the water managers were aging, over 65 years old, and were having difficulty in maintaining farm ponds and their water management (Taniguchi et al., 2011). Using hydroelectric power to support the operation and maintenance an irrigation pond, replacing manpower, and fuel with electricity would be one of the best ways to to generate electricity at a farm pond. Moreover, some water managers havd problems with illegal disposal of cabbages into the ponds and illegal fishing by fishermen who deliberately discharged water to lower the water level in the ponds for easier fishing. However, since the location of irrigation ponds were far from the villages, water managers could not check the ponds often.

Pic. 1 Installation of an electric bulb
(*Left: outlines of hydroelectric system*)

Pic. 2 Outlines of the monitoring system

Pic. 3 View of a live camera through smartphone

Considering those conditions, an electric bulb and monitoring system with water level sensor and live view camera was installed. Through the monitoring system, water managers could check the water level of their irrigation ponds and also watch the conditions of water intake and its surroundings through a computer or smart phone if the internet connection was available. A monitoring system was installed at Yanaka irrigation pond, which had a water level sensor and live view camera. Users could check the water level and view of the irrigation pond through the internet connection. The system required 200W for its operation.

Pictures 1, 2, and 3, show the electric bulb, monitoring system, and the view of irrigation pond through smart phone, respectively.

CONCLUSION

Hydropower potential using irrigation pond was estimated. Estimated electric power output and electric power were different at the ponds with similar storage capacity due to different water management. Field experiment of siphon intake generation was also conducted and constant power output was generated. Using hydroelectric power to support the operation and maintenance of a farm pond, replacing manpower and fuel with electricity, would be one of the best ways to generate electricity at a farm pond.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge financial support from “Community Contribution Support Activities”, Tottori University and technical supports from Tottori Institute of Industrial Technology and Asahi Organic Chemical Industry Co. Ltd.

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