

## Mini Hydraulic Power Enterprise of Elis Inc.

### Introduction

We, Elis Inc., specialize in clean and ecological generation of electricity as one of group businesses led by a gas corporation, which have sixty-eight-year history as LPG supplier in Okayama city. While the main business of the group is to provide thermal energy in the form of gas, our goal is to develop new technology, mini hydroelectric power generation, based on solar panel electricity systems using recently developed power-generating technology. Our mini hydroelectric power generation system is trademarked as “WaterWeco” coined to denote Waterwheel + Ecology + Economy.

### Business Domain of “WaterWeco”

Our mini hydroelectric power generation enterprise started in 2009, before the inauguration of Feed in Tariff (FIT) due to the Great East Japan Earthquake. At first, the enterprise aimed at reducing greenhouse gases as corresponding to the Kyoto Protocol regulated in 1997 and just focused on hydroelectricity and the creation of hydraulic power from water streams using natural geographical features without a large-scale dam that requires destructions of nature. Therefore, the president of Elis Inc, went to the Alpine region in Europe, which is an area advanced in hydroelectric power generation, and inspected the medium or small scale hydroelectric power plants and manufacturers of generators in the Danube basin.

The photo above is of a small hydroelectric power plant located in the central part of the Augsburg city area in Germany. Since the inauguration of FIT, small hydroelectric power plants have spread rapidly in Germany despite its geographic and climatic conditions such as less perspiration compared to Japan and little difference in elevations. According to documents, there are fifteen- to twenty- thousand plants which generate tens of kW. The document noted that a generator producing 30 kW caused so little rotating noise that a person did not hear the sound even when in closer proximity. The author was impressed by the aspect of an ecological recycling of energy harmoniously existing in a quiet urban area. With the knowledge he gained there, the president himself formulated the business plans below. At the time of stating our business plan, small hydroelectric generation was defined as 1000kW or less. Our research revealed that hydroelectric power plants in Okayama, which include ones using dams, generating 30kW or more have already been developed by the Chugoku electric power company and Okayama prefecture after the Meiji era in the late 1860s. That means manufacturers of special apparatus and plant facilities do exist. However, it seemed generators smaller than that do not exist. Therefore, we recognized our mini hydroelectric generator as a business field and defined our

products as micro hydroelectric generator from that point.

There have always been wooden water mills in the peaceful landscapes of Japanese heart. According to one document, approximately eighty thousand wooden water mills were used for paper making or flour milling during the early Showa Era (circa 1930) before the oil industry revolution. Our company set up a traditional water wheel that generates 7.5 kW in an agricultural water channel, where a water mill previously existed to make paper, at Takao, Niimi-city in Okayama two years ago.

\*In the figure below, a fixed blade Kaplan turbine is the same as fixed propeller turbine.

<Figure>

### The potential of micro hydroelectric generator

A hydroelectric power generator is suitable for regions where rivers do not dry up, due to regular rainfall throughout the year. Although it cannot be installed everywhere, like solar panels can, it can generate electricity at night or on rainy days unlike those panels. A suitable place for a hydroelectric power generator has some level and constant water flow throughout the day. It is a base load power with little change of energy generation.

During the dry season which is typical of agricultural water usage, the amount of electricity generation by a micro hydroelectric generator will be less than during the ample rain season. Nevertheless, it promises to provide sufficient quantities of electricity in comparison with solar panels. Moreover, it has become easier to acquire water rights for electricity generation in Japan. The New Energy Foundation in Japan conducted an investigation commissioned by the Agency of Natural Resources and Energy of Ministry of Economy, Trade and Industry, and their report in March 2009 suggested the usage of industrial water and sewerage as a promising new area.

### Understanding the needs for micro hydraulic generation

Since the enforcement of Paris Climate Accord, investment in environmental energy such as ESG investment has rapidly increased globally. In Japan, nationwide surveys to find appropriate places are conducted mainly by local governments.

Currently, Ministry of the Environment is also planning to release the potential map including results of environmental assessments. However, agricultural water managed by an agricultural water management association, public waterways in parks or industrial water are more appropriate for micro-level hydraulic generators. The electricity is suitable not only for retailing purposes but also as a possible power source for small electric vehicles, electrical lawn mower, and agricultural greenhouses.

### Selecting necessary equipment for micro hydraulic generators

As we actually started the business as a retailer of micro hydraulic generators, basic equipment such as water wheel or generator was not available on the market because everything needs to be small. Therefore, we needed to develop them as our own products. In other words, the business does not develop only by dealing equipment like solar power generators, for which a lot of manufacturers compete on technological development. The only available commercial products for micro hydraulic generator are the followings: battery chargers corresponding to output of 100 V / 12 V dc single-phase lead-acid battery sold for car or camping suppliers and 12 V dc standardized lead-acid batteries, inverters of 12 V dc input and 100 V, 50/60 Hz single-phase output. Alternators as DC generators for automobiles work with high-speed engine drive such as gasoline or diesel; thus they are not compatible to low-speed engine like open waterwheel without casing for open channel such as agricultural water channel. That means the necessity of developing generators corresponding to low-speed engine, whose open speed without loading is generally 10 rpm – 60 rpm depending on the size of diameter and striking place (over, breast, or under) and 5 rpm – 30 rpm with loading up to half speed. Furthermore, we also developed battery charger with 10 A because the range of commercial products seemed to be up to 12 Vdc, 8 A.

### Description and Characteristics of Our Product

#### A) Development of slow-speed compatible Elis-style generator

We began to develop generators, named Elis-style, starting from 500 W capacity generators. The function and structure are single-phase output of 100 V, 50/60 Hz so that a generator can directly supply electricity to commercial electrical appliances just by rotating it. The loading speed of the water wheel is set to 5 rpm~30 rpm with 30 – 60 times speed increasing rate. Therefore, we expected the loading speed of generator to reach between 300 rpm~900 rpm and set the synchronous speed. Consequently, the generator is designed as a rotary multi-pole synchronous generator based on the rules of electromagnetic induction of Faraday with 12-, 18-, and 20-poles. In that case, 50/60 Hz would rotate a 12-pole motor at synchronous speed of 500/600 rpm, 333/400 rpm for a 18-pole motor, and 300/360 rpm for a 20-pole motor. For a magnetic pole, a neodymium permanent magnet, which has recently been developed and on a market, is adopted to create a fixed field system without field control. It is because a neodymium permanent magnet generator has become practicable with an incredible ten times the magnetic force of a conventional ferrite permanent magnet. The structure is laminate stake holding structure of electromotive coil disk and permanent magnet disk in an alternate sequence on a rotating shaft which our factory is capable of manufacturing. First, we completed a generator producing 500 W. Then, generators producing 1 kW, 3 kW and 5 kW were developed in a way that unified several

500 W generators in parallel. 3 kW and 5kW were chosen to match the base unit of solar power generation for households. A 5 kW generator weighs approximately 100 kg, thus, we concluded it impossible to increase capacity also in respect of cost. The big difference of our product from other manufacturers', our rotational mechanism is simple structure which would not require constant checks and maintenance. Therefore, the maintenance cost can be reduced. Moreover, the component parts for field control can be reduced, speed increasing rate may be kept low, resulting in the reduction of cost for an increaser. The last difference is the structure. 1) The less cogging torque because of the coreless coil and no iron loss but only with copper loss because of the vinyl chloride body makes high efficient energy conversion. 2) While a multi-pole low-speed coreless generator of other manufacturers is, namely, the outer rotor style with outside magnet disk for which a belt is installed over and rotate the motor, Elis-style generator placed magnet disks inside and rotate the motor through a gear of small diameter or a pulley, called inner rotor style. Since the inner rotor style can be combined with low-speed water wheel, an Elis-type generator can get higher speed increase rate, which is the difference and merit of Elis-type generator compared to other coreless generators.

#### B) Development of Elis-style water wheel

As a micro hydraulic generator for business development based on agricultural water channel, there are open water wheels without casing. The wheel diameter ranges from approximately 1 m to 5 m or so, and the width ranges from about 0.5 m to 2 m or so. There are 8 to 32 turbine impellers and three shot types (over, breast, under) depending on the water pouring position. As a characteristic of an open water wheel in a open water channel, it is easier to take measures with dust than wheels for closed water channel such as a propeller water wheel in a closed water road. According to our empirical experiment, a bottom fixed propeller turbine needed overhaul on a regular basis although a dust screen was attached. For a micro hydraulic generator of this size, it extremely increases the cost to automate dust countermeasure. The dust countermeasure also requires additional labor costs for specialists, which may cause fatal influence on the money flow.

To solve the problem of maintenance cost and reduce construction works, we decided to focus on researching and developing an open water wheel that can reduce initial cost. From our experience of the empirical experiment, we learned that the shape, number, and angle of propellers make a huge difference to electricity generation efficiency. Thus, we tried to optimize them.

Building an open water wheel requires neither to construct a dam nor to elevate the bank. A water wheel is originally a piece of equipment to convert hydraulic energy into kinetic rotational energy based on the Bernoulli's hydraulic principle. Thus, it has fundamentally been discussed how to efficiently convert the potential energy of the water channel holding the water wheel or

the difference of height between inlet and outlet into kinetic rotational energy. From our experiments, the general efficiency seems to be 60 % for overshot and 30 % for undershot.

Then, to further increase the efficiency of open water wheel, we conducted research in cooperation with West Japan Fluid Engineering Laboratory Co., Ltd. This company holds a lot of knowledge of research and development about passing water tank conducted by Nagasaki University, which has achievements in researching and developing small-scale wind power generators. The company is also equipped with the latest research facilities.

One of two types of “WaterWeco” is an undershot water wheel with 17.4 % higher efficiency than competitors. It was presented at the annual conference of The Japan Society of Mechanical Engineers in 2017 by Nagasaki University. The other type is a breast shot water wheel with the highest efficiency ever. As the new undershot one, it was commercialized by applying the best results of numerical analysis, fluid analysis and model experiments.

Efficiency was tested using a scale model with the same flow conditions such as the water flow and fall as our breast shot water wheel which has been working at an agricultural waterway in Takao, Niimi-city, OKAYAMA for 2.5 years. Moreover, the third party organization certified the efficiency, which means that efficiency result of the environmental technological verification (ETV) program by Ministry of the Environment marked approximately 25 % to 30 % and proved to be the same as our scale model experiment result. In addition, efforts have been made to reduce costs.

Our Niimi-model has been working for 2.5 years. We have changed the layout of water wheel after the ETV program as applying the numerical analysis result, and succeeded in approximately 1.0 kW improvement of electricity generation. Current maximum electricity generation is 5.0 kW. If we installed the newly developed pitch flap propeller, it was theoretically proved that the electricity generation would become larger than the situation of stagnation\*.

To calculate the conversion rate of currency when selling the generated electricity, it would be 34 yen / kW in case of current FIT and 14 yen / kW in case of substitute electric power for agriculture. The latter case would be taking into account the various subsidies if it was used for a communication apparatus or small EV at the time of emergency; then, the initial cost would be reduced at most the third.

\*The situation of stagnation means a water wheel is immersed in water. The water wheel in the agricultural water way of Takao, Niimi-city is being immersed in water, and we verified the influence of stagnation to the efficiency of a water wheel using a scale model.

### C) Speed increaser

In case of a micro hydraulic generator, rotational speed of a water wheel at the

combination of rotational shafts of water wheel and generator becomes slower than the standardized rotational speed of generator, 30 ~ 60 times increase of speed is required. For this problem, we considered to inversely apply a speed reducer, which has become common usage, or use a speed increaser for wind power generators, for which the research has been progressed following the solar power generators. However, we found that a specialized manufacturer of gear structures sell a commercial product, and decided to use it. However, it would become deemed direct connection with water wheel shaft and costs comparatively expensive; thus, we have to choose from the following: 1) placing a generator apart on the water wheel frame and conducting the first speed increase with the combination of sprocket and driving chain and the second increase with an increaser of a specialized manufacturer, 2) conducting both the first and second speed increase with the combination of sprocket and driving chain.

The increaser from the manufacturer is capable of up to 40 times for 300~500 W and 30 times for 1~5 kW of Elis type. For out of range of Elis type, it is capable to increase 30 times for over 5 ~20kW and 6 times for 22 kW. However, we concluded that it would be more reasonable and easier to maintain if we use a combination of sprocket and driving chain with the condition of maximum three steps of increase ( $3 \times 3 \times 3=27$ ,  $4 \times 4 \times 4=64$  times), because we were uncertain about durability and maintenance.

#### Further product development corresponding to the change of business environment

Our business environment drastically changed since the Great Eastern Japan earthquake in March, 2011. Nuclear power generation, which has been considered as the leader of low carbonization, lost power, and the forced FIT was executed to include ecological electrical power generation. That means the occurrence of selling electricity.

The selling price of electricity by a small-scale hydraulic generator dramatically increased to about 34 yen / kWh from 5 yen / kWh of before FIT. A new technological field occurring as a result of this change is to develop technologies and products for unification with wires of electric power companies. It would be a correspondence for OEM from manufacturers of power unit.

#### System of converter-inverter style

In general, small-scale hydraulic generators from major electric appliance makers (other manufacturers) are few-pole permanent magnetic three-phase synchronous generators with standard synchronous speed of 1000 rpm ~ 1800 rpm and standard outlet voltage of 200 / 220 V, 50 / 60 Hz.

Thus, a high-speed generator for Elis-style would produce 100V with 500 rpm ~ 900 rpm and 50V with 250 rpm ~ 450 rpm.

Therefore, to generate electricity using generators from other manufacturers with Elis water wheels, we have to convert three-phase AC of approximately 50V to DC, then invert to three-phase 200V or single-phase 100V, 50/60 Hz so that it can interconnect with systems of electric power companies and sell electricity.

We described this system as the converter-inverter style. Our company is ready to adjust our system to correspond to this style using electrical appliances from other manufacturers.

#### Introduction examples

最後の注釈のみ

\*As a cooperative business with Tsuyama-city, Okayama, we used effluent from a power plant of JA Tsuyama. This provides electrical power for EVs on a campsite that does not use commercial power supply. This would empirically study the possibility as a substitute of GS electricity charging facility for EV in places where there are few gas stations.

#### Future prospect

Currently, business field of Elis Inc. are as follows: 1) sales of Elis-type open current water wheels and Elis-style standard generators, 2) sales of micro hydraulic generator units which consist of Elis-style standard water wheel and generator and generates 0.3 kW ~ 5.0 kW in various open water ways, and 3) sales of micro hydraulic generator units generating 2.2 kW ~ 22.0 kW. We also build micro hydraulic generator at our own cost and earn incomes to pay for user fees of water ways by selling the electricity. Recently, the government of Japan has increased the range of special tax measures and subsidy system for local production for local consumption models. We aim to popularize the usage of electric power not only for electric vehicles but also for electrical mowers, agricultural greenhouses, and as a back-up power source for restoration after disasters. Moreover, we are developing an electronic payment system for charging EV, so it is possible to it together with solar power generation. In future, we plan to improve efficiency and reduce cost so that we can build a substitute EV charging facility for secluded places in the mountains, in which there are few gas stations because of depopulation.