Developing a Portable Hydroelectric Generator Using Axiomatic Design Method

H Soewardi\(^1\) and E A Putra\(^2\)

1,2 Department of Industrial Engineering, Faculty of Industrial Technology, Islamic University of Indonesia, Yogyakarta, Indonesia
Email: \(^1\)hartomo@uii.ac.id, \(^2\)enggangaditya@gmail.com

Abstract. Hydroelectric power plant is the largest renewable energy source in Indonesia. There are several models of hydroelectric power machine applied in Indonesia, one of them is a portable generator. However, there are still some problems in the existing portable design, for example it has a big size and unattractive design; it is unpractical and unsafe to use, that it results in ineffective and inefficient use of the generator as well as results endanger. This reality occurs because the design does not meet user criteria. The purpose of this study was to redesign the portable hydroelectric power generator which can satisfy user requirements. Survey was conducted to identify the customer needs and axiomatic design method was used to determine the design parameter by mapping process from customer attribute and functional requirement. Statistical analysis was conducted to test the hypothesis. The results of this study showed that the proposed design of portable generator can increase user satisfaction as much as 73.67% so it is recognized to be different from the existing design. The design developed is also valid to satisfy user requirement at 5% significance level including the fact that it is durable, waterproof, attractive, lightweight, small in size, and portable.

1. Introduction

Electricity is one of the main points that human requires to help with daily activities [1]. The Indonesian government targets the level of electricity consumption in 2025 reaching 1,500 kWh per capita. Meanwhile, the electricity demand per year is 468,067 GWh. However in the end of 2015, the consumption level of electricity in Indonesia was still about 880 kWh per capita [2]. Thus government is intensively building a new power plant to achieve the target on time. Currently, about 87% of the electricity supply is dominated by the use of fossil fuels especially petroleum and coal [3]. Meanwhile, the unlimited source of renewable energy has not been utilized optimally [4], that is only 17.4% of the 65.764 MW of potential hydroelectric energy is used. Such thing occurs because of high cost and unreachable locations for investment [5]. One of its solutions is by using portable generator [6]. Portable generator is a device to generate an electrical energy by combining an electrical generator and propulsion which is packed simply [7]. The propulsion has a function to trigger the generator by using a high water flow. It is frequently known as portable hydroelectric generator. However there are still some problems in the existing generator. Based on the preliminary study, it is found that 59.2% of the users said that the device is unpractical, 18.8% said that the device has a big size, 12.1% said that the design is unattractive, 9.9% said that this device is unsafe to use. This fact indicates that the portable generator has been ineffective, inefficient, and dangerous to use. Thus this is crucial to improve its design.

Some previous studies had been done. [8] conducted a study about a hydroelectric generator by using low water energy. This research focused on the development of turbine type and generator type, as well as the development cost. In addition, [9] developed a portable hydroelectric generator by using a
cross flow turbine but they did not discuss the power generated. [10] studied a design of hydroelectric generator by using a spiral shape of hydro coil turbine to produce energy. Portable generator was also developed by [11] by using a polymer electrolyte membrane fuel cell (PEMFC). This prototype could generate energy up to 500 Watt per hour at temperature between 60-80 °C. [12] designed a portable generator based on a chemical reaction from micro direct ethanol fuel cell (Micro-DEFC). The result of this study showed that the chemical reaction produces electricity reaching 0.9 mV and this chemical reaction depends on temperature. All these studies focus only on the design of portable generator in producing energy regardless of users’ requirements in use. The objective of this study was to redesign the portable hydroelectric generator to have a more effective, more efficient and safer generator by using axiomatic design method.

2. Research method

2.1. Survey
Paper based survey was conducted to identify the customer attribute of portable hydroelectric generator and also to validate the proposed design by distributing a questionnaire.

2.2. Apparatus
Some equipment used in this study, there are:
- SPSS software 20 version was used to conduct statistical analysis.
- Sketch up Pro 2017 software was used to design the virtual prototype.
- Questionnaire, was devided into two stages. The first was to identify the customer needs and the second was to validate the prototype design

2.3. Axiomatic design method
Axiomatic design is a theory that is used to develop a new product that consumers require by mapping into four domains [13], [14]. The four domains used in axiomatic design can be shown in the Figure 1.

![Figure 1. Domain in Axiomatic Design, [14]](image)

Customer domain is a domain that contains customer attribute. Functional domain is a domain that contains all functions to be provided in a product. Meanwhile, physical domain is a domain used to realize the Functional Requirement. In addition, process domain is a domain that explains how to make the product based on physical domain [14]. These domains are connected by using zigzagging process.

2.4. Statistical analysis
There were two kinds of statistical tests used in this study. They were Marginal Homogeneity and Wilcoxon test. The marginal homogeneity test was used to test the null hypothesis (Ho) whether the proposed design was in accordance with the customer requirements [15]. Meanwhile the wilcoxon signed rank test was used to test the null hypothesis (Ho) whether there was a difference between the proposed design and the existing design of the portable hydroelectric generator [16].
3. Result and discussion

3.1. Result of survey

Paper-based survey found that there are six attributes that is used to redesign the portable hydroelectric generator. They are durable, waterproof, attractive design, lightweight, small size, and easy to carry. According to the Indonesian dictionary, durable defined as the ability of a product to be not easy damaged and has a long life. Meanwhile, waterproof is the addition of synthetic organic polymers into a material to prevent the leakage [17]. While Attractive design defined as a strategy used to increase the value of a product [18]. Lightweight allows the user to lift or carry product easily. Small size allows the user to not require a spacious place to keep or using the product. And easy to carry allows the product being practical to carry before or after use.

3.2. Mapping process of the functional requirement to design parameter.

In the mapping process, customer attribute (CA) was translated into functional requirement (FR) and then the design parameter (DP) determined to realized the Functional Requirement. Mapping process was explained in this following sub-subsections.

3.2.1. Design parameter for satisfy CA1: durable

Figure 2 shows the hierarchical structure of mapping process from FR1: improving the product endurance to DP1: Durable product.

Based on figure 2, the design parameter of turbine is made from the iron material (DP1.1.2). This material has a function to protect the turbine from the object that can inhibit the turbine spin (FR1.1.2). While the body is of from plastic material (DP1.1.1). This material has a function to protect the body and turbine from cold or hot temperature (FR1.1.1). A sturdy material (DP1.1) is needed to improve the resistance from the environmental changes (FR1.1).

3.2.2. Design parameter for satisfy CA2: waterproof

Figure 3 shows the hierarchical structure of mapping process from FR2: improving the leakage resistance to DP2: waterproof material.

Based on figure 3, design parameter of the body are made from the abs plastic waterproof material (DP2.1.1). This material has a function of holding water get into the machine (FR2.1.1). Hydroelectric
generator requires high fiber material (DP2.1) to improve the resistance on the water flow (FR2.1) and also to improve the leakage resistance (FR2).

3.2.3. Design parameter for satisfy CA3: attractive design

Figure 4 shows the hierarchical structure of mapping process from FR3: Provide the unique in design and features DP3: Innovative design.

Based on Figure 4, design parameter of the turbine has 3 blades (DP3.1.1.1) which are used to get an efficient of turbine spin (FR3.1.1.1). This portable hydroelectric generator is designed with a tube shape (DP3.1.1) to maximize the turbine spin (FR3.1.1) and minimize a friction against the water flow (FR3.1). To provided an attractive design color (FR3.4), this product uses a color combination between white (248,243,222) and brown (74,0,12) (DP3.4). This product used a round power button with a deep basin (DP3.2.1) and white color (DP3.2.1.1.2) to improve the clarity (FR3.2.1.1.2). The power button has diameter of 2.75 cm (DP3.2.1.1.1) to prevent discomfort able of the fingers (FR3.2.1.1.1) and also used to minimize the miss click intensity (FR3.2.1). Furthermore, this product also used white LED Light (DP3.2.2) to Minimize the energy usage for indicator light (FR3.2.2). The power button and LED Light has a function to provide an easiness in operation (FR3.2).

As the energy storage, this product uses deep cycle battery (DP3.3.1) for an efficient energy storage (FR3.3.1) to maximize the energy storage (FR3.3)

3.2.4. Design parameter for satisfy CA4: lightweight

Figure 5 shows the hierarchical structure of mapping process from FR4: make it easy lift or carry the product to DP3: lightweight design.

Based on Figure 5, design parameter of the turbine has 3 blades (DP3.1.1.1) which are used to get an efficient of turbine spin (FR3.1.1.1). This portable hydroelectric generator is designed with a tube shape (DP3.1.1) to maximize the turbine spin (FR3.1.1) and minimize a friction against the water flow (FR3.1). To provided an attractive design color (FR3.4), this product uses a color combination between white (248,243,222) and brown (74,0,12) (DP3.4). This product used a round power button with a deep basin (DP3.2.1) and white color (DP3.2.1.1.2) to improve the clarity (FR3.2.1.1.2). The power button has diameter of 2.75 cm (DP3.2.1.1.1) to prevent discomfort able of the fingers (FR3.2.1.1.1) and also used to minimize the miss click intensity (FR3.2.1). Furthermore, this product also used white LED Light (DP3.2.2) to Minimize the energy usage for indicator light (FR3.2.2). The power button and LED Light has a function to provide an easiness in operation (FR3.2).

As the energy storage, this product uses deep cycle battery (DP3.3.1) for an efficient energy storage (FR3.3.1) to maximize the energy storage (FR3.3)
Based on figure 5, design parameter weight of the product is between 3.5-4 kg (DP4.4.1) to minimize the injury when the product lifted (FR4.4.1). It is important to design a lightweight product (DP4.1) to provide an easiness to lift the product (FR4).

3.2.5. Design parameter for satisfy CA5: small size
Figure 6 shows the hierarchical structure of mapping process from FR5: easily stored to DP3: Adjustable Design.

3.2.6. Design parameter for satisfy CA6: easy to carry
Figure 7 shows the hierarchical structure of mapping process from FR4: practical to carry before or after use to DP3: ergonomic design.

Based on figure 6, design parameter of the product has 2 levels of form adjustment (DP5.1). They are closed turbine and opened turbine. The closed turbine has length 32 cm (DP5.1.2.1) with the function is to reduce space for saving the product (FR5.1.2.1), and the other form has length 36 cm (DP5.1.1.1) with the function to provide space for the water flow from the turbine section (FR5.1.1.1). The purpose of these 2 levels of form adjustment is to provide the product to be practicality in use (FR5).

3.3. Virtual design of portable hydroelectric generator
After mapping process, the next step is creating a virtual design of Portable Hydroelectric Generator based on the design parameters that have been mapped in the previous process. The virtual design of Portable Hydroelectric Generator shown on figure 8.
3.4. Result of validation.

There are two kinds of statistical test used in this study. They are Marginal Homogeneity and Wilcoxon test. Table 3.1 present the result of marginal homogeneity test and table 3.2 present the result of Wilcoxon test.

Table 1. Marginal homogeneity test result

| Attribute     | Asymp.sig (2-tailed) |
|---------------|----------------------|
| Durable       | 0.11                 |
| Waterproof    | 0.190                |
| Attractive Design | 0.137               |
| Lightweight   | 0.09                 |
| Small Size    | 0.61                 |
| Easy to carry | 0.12                 |

Based on the table 3.1, can be seen that the asymp.sig (2-tailed) value of the attributes > 0.05. It means that Ho is accepted so it is possible to conclude that the proposed design of portable hydroelectric generator can meet what the users require.

Table 2. Wilcoxon signed rank test result

| Attribute     | Asymp.sig (2-tailed) |
|---------------|----------------------|
| Durable       | 0.00                 |
| Waterproof    | 0.03                 |
| Attractive Design | 0.00                |
| Lightweight | 0.01 |
|-------------|------|
| Small Size  | 0.01 |
| Easy to carry | 0.00 |

Based on the table 3.2, can be seen that the asymp.sig (2-tailed) value of the attributes < 0.05. It means that Ho is unaccepted so it can concluded that there is a difference between the proposed design and the existing design of portable hydroelectric generator. It means the proposed design is more durable, more waterproof, more attractive, lighter, smaller, and easier to carry such that it can increase satisfaction of users as much as 73.67%.

4. Conclusion

Conclusions of this study are as follow:
There is six attributes that customer required to redesign the portable hydroelectric generator. They are durable, waterproof, attractive design, lightweight, small size, and easy to carry
Design parameter for a durable attribute is an iron material for turbine and plastic material for the body. Then, design parameter for a waterproof attribute is high fiber material that is abs plastic for the body. For attractive design attribute, design parameter is tube form on the body with a color combination between white (248,243,222) and brown (74,0,12), 3 blades on the turbine, a round power button with a deep basin, white LED light, and deep cycle battery as the energy storage. Design parameter for a lightweight attribute is the product weight between 3.5-4 kg. While design parameter for small size attribute has 2 levels of form adjustment. If the turbine used, the length of product 36 cm, but when the turbine is not used, the length 30cm. form adjustment was controlled automatically And design parameter for easy to carry attribute are rubber handle with a dimension of width 7.62 cm and diameter 4.34 cm.

The proposed design of portable hydroelectric generator is valid to satisfy the user requirement and increase satisfaction of users as much as 73.67% which it is more durable, more waterproof, more attractive, lighter, smaller, and easier to carry such that it can increase satisfaction of users as much as 73.67% at 5% of significant level.

5. Reference

[1] Hasanov, F. J., & Mikayilov, J. I. 2017. The Impact of Age Groups of Consumption Residential Electricity in Azerbaijan. Communist and Post-Communist Studies 50, 339-351.
[2] Gultom, T. T. 2017. Pemenuhan Sumber Tenaga Listrik di Indonesia. Jurnal Ilmiah Research Sains 3(1), 130-138.
[3] BPPT. 2016. Outlook Energi Indonesia 2016. Jakarta : Badan Pengkaji dan Penerapan Teknologi.
[4] KESDM. 2015. Statistik Ketenagalistrikan Tahun 2015. Jakarta: Kementrian Energi dan Sumber Daya Mineral
[5] BPPT. 2017. Outlook Energi Indonesia 2016. Jakarta : Badan Pengkaji dan Penerapan Teknologi.
[6] Shantika, T., & Ridwan, M. 2013. Perancangan Prototipe Pikohidro Portable 200 Watt. Seminar Nasional XII Rekayasa dan Aplikasi Teknik Mesin di Industri, 39-48
[7] Balansay, M. L., V., Añonuevo, M. R., Q., Cuenca, R., M., & Garbin, R. V. 2015. Portable hybrid Powered Water Filtration Device. Asia Pacific Journal of Multidisciplinary Research 3(3), 136-140.
[8] Zhou, D., & Deng, Z. D. 2017. Ultra-Low-Head Hydroelectric Tecnology : a Review. Reneable and Sustainable Review 78, 23-30
[9] Patel, S. U., & Pakale, P. N. 2015. Study on Power Generation Using Cross Flow Water Turbine in Micro Hydro Power Plant. International Journal of Research in Engineering and Technology 4(5), 1-4.
[10] Apprilianto, A., Indarto., & Prajitno. 2013. Design of Prototype Hydro Coil Turbine Applied as Micro Hydro Solution. ASEAN Journal of System Engineering 1(2), 72-76.
[11] Devrim, Y., Devrim, H., & Eoglu, I. 2015. Development of 500 W PEM Fuel Cell Stack For Portable Power Generators. *International Journal of Hydrogen Energy* 40, 7707-7719.
[12] Saisirirat, P., & Joommanee, B. 2017. Study on the Performance of the Micro Direct Ethanol Fuel Cell (Micro-DEFC) for Applying with the Portable Electronic Devices. *Energy Procedia* 138, 187-192.
[13] Soewardi, H., & Pradana, V. 2016. Developing Features of Water Faucet by Using User Centered Design Approach. *ARPN Journal of Engineering and Applied Sciences* 11(7), 4734-4738.
[14] Lee, D. G., & Suh, N. P. 2006. *Axiomatic Design and Fabrication of Composite Structures: Application in Robots, Machine Tools, and Automobiles*. New York: Oxford University Press.
[15] Yamin, S., & Kurniawan, H. 2009. *SPSS Complete*. Jakarta: Salemba Infotek.
[16] Sheskin, D. 2004. *Handbook of Parametric and Nonparametric Statistical Procedures Third Edition*. Washington: Chapman & Hall/CRC.
[17] Wang, W., Zhao, Y., Liu, H., & Song, S. 2017. Fabrication and Mechanism of Cement-Based Waterproof Material Using Silicate Tailings From Reverse Flotation. *Powder Tecnology* 315, 422-429.
[18] Ceschin, F., & Gaziulusoy, I. 2016. Evolution of Design for Sustainability: From Product Design to Design for System Innovations and Transitions. *Design Studies* 47, 118-163.