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Implementation of Fuzzy Sugeno Method for Power Efficiency

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Abstract— *Energy is one of the basic needs for human being. One of the most vital energy sources is electricity. Electricity is a type of energy that sustains survival of human being, more particularly in industrial sector. Efficiency in industrial sector refers to a state where electricity is used to as little as possible to produce the same amount of product. The case study was conducted in marine commodity sector, anchovy and jellyfish supplier. The supplier was classified as SME that installed 33,000 VA electric powers (B2). The data were in the form of energy consumption intensity (ECI) and specific energy consumption (SEC) to determine the energy efficiency level. The objective of the study was to classify the efficiency level of electricity consumption using Sugeno Fuzzy method. The findings of the study were 1) the average ECI between January, 2016 and April, 2017 was 1,949 kWh/m2; it was classified as efficient; 2) the average SEC at the same period was 126,108 kWh/ton; it was classified as excessive. Sugeno Fuzzy logic was implemented to determine efficiency level of electricity in this company. Based on the average ECI and SEC, the electricity consumption of the company was categorized as excessive with FIS Sugeno output of 0.803.*

Keywords— Electrical Power, Efficiency, Fuzzy Sugeno, ECI, SEC

I. INTRODUCTION

Energy is one of the basic needs for human being. One of the most vital energy sources is electricity. Electricity is a type of energy that sustains survival of human being, more particularly in industrial sector. Efficiency in industrial sector refers to a state where electricity is used to as little as possible to produce the same amount of product. The case study was conducted in marine commodity sector, anchovy and jellyfish supplier. The supplier was classified as SME that installed 33,000 VA electric powers (B2). In 2015, the marine commodity supplier consumed 14,534 kWh of electricity and produced 133,460 kilograms of anchovy and jellyfish.

This study described the use of electricity during production, the energy consumption intensity (ECI) and specific energy consumption (SEC) to determine efficiency level of electricity. The findings were efficiency level of electricity consumption in the company (marine commodity supplier) as well as to evaluate whether or not Sugeno FIS algorithm was applicable in this case study. The supplier may use the findings to evaluate how much electricity they use during production, maintenance and for operating their electrical appliances.

II. METHODOLOGY

Electrical Energy

Electrical energy is type of energy generated from the flow of electrical charges. Energy is ability to do an activity or apply certain power to move an object. In terms of electrical energy, force is the attraction of electricity or repulsion between charged particles. Electrical energy can be either potential energy or energy, which is usually stored as potential energy, stored in relative positions of charged particles or electric fields.

Charged particles moves through wires or other media called current or electricity. In addition, there is static electricity, which results from an imbalance or separation of positive and negative charges on an object. Static electricity is a form of electrical potential energy. If enough charge accumulates, electrical energy can be released to form sparks (or even lightning), which have electrical kinetic energy.

Energy Consumption Intensity (ECI)

Energy Consumption Intensity (ECI) is the division between energy consumption and total area of a building (SNI 03-6196, 2000). Energy consumption refers to the amount of energy consumption of both electrical energy and other energy sources in one building within one year.

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Electricity consumption for one year (KWH / year) is obtained from electricity bill, while other energy consumption is obtained from records of fuel consumption or consumption of other energy sources.

Energy Consumption Intensity (ECI) is term used to describe the amount of energy used per square meter of gross total area of a building within certain period of time (per year or per month).

$$\mathrm{ECI}\left(\frac{kWh}{m^2}\right) = \frac{\text{total energy consumption } (kWh)}{\text{total area of a building } (m^2)}$$

Specific Energy Consumption

Specific energy consumption (SEC) is the amount of energy used for production. These elements are used to measure specific energy consumption (SEC) of an industry.

1. Energy consumption of an industry for certain period of time (kWh/period of time, GJ/period of time)
2. Total production for certain period of time (ton/period)

The following equation can be used to measure the specific energy consumption (SEC) of an industry.

$$\mathrm{SEC} = \frac{\text{total energy consumption } (kWh)}{\text{total production } (ton)} \qquad (2)$$

Fuzzy Sugeno

Sugeno Fuzzy method is fuzzy inference method for rules represented in the form IF-THEN, where system output (consequently) is not in the form of fuzzy set, but rather a constant or a linear equation. This method was introduced by Takagi-Sugeno Kang in 1985. [6] Sugeno model uses the Singleton membership function, membership function of which membership degree is 1 on a single crisp value and 0 on another crisp value.

Zero-Order Sugeno Fuzzy Model

In general, the equation for the zero-order Sugeno Fuzzy model is IF (x1 is A1) • (x2 is A2) • (x3 is A3) • ... .. • (XN iS AN) THEN z = k. A1 is the set of I[th] fuzzy as antecedent and k is a constant as a consequence. Advantage of the Sugeno-type FIS is zero-order is often sufficient for various modeling purposes. [7].

III. RESULT AND IMPLEMENTATION

Data Management

This study uses Fuzzy Logic, particularly Fuzzy Inference System (FIS) with zero-order Sugeno Method. Fuzzy logic is often used to calculate vague score. In accordance to the Fuzzy Logic theory, the theory requires input score, input variable and linguistic variable. This study involves various processes or stages of the zero-order Sugeno method, from the start until the end. The stages are as follow:

A. Preparation

Prior to ECI and SEC data input to Sugeno FIS method, the researchers should do these steps.

1. Calculating ECI and SEC score

Table 1 described the 2015 ECI and SEC score of the marine commodity supplier.

Table 1. 2015 ECI and SEC of the Company

No	Month	ECI (kWh/m^2)	SEC (kWh/ton)
1	January	3,504	125,824
2	February	4,574	110,997
3	March	5,522	97,637
4	April	1,880	107,033
5	May	1,864	106,955
6	June	1,249	85,853
7	July	2,125	111,385
8	August	2,078	118,159
9	September	1,419	97,652
10	October	4,762	111,935
11	November	3,793	122,810
12	December	1,438	100,892
	Total	**34,207**	**108,932**
	Minimum	**1,249**	**85,853**
	mean	**2,851**	**108,094**
	Maximum	**5,522**	**125,824**

2. Classifying the ECI and SEC variables

Having obtained the ECI and SEC scores, the following stage was to classify ECI and SEC variables. Standardized ECI for non air conditioned room from the Department of Education and Culture was used as reference for ECI variable classification since the supplier did not use any air conditioner. Table 2 described the criteria for the ECI variable.

Table 2 ECI Variable Criteria

Kriteria	Range of ECI
Very efficient	0,84 s/d 1,67
efficient	1,67 s/d 2,50
Excessive	2,50 s/d 3,34
Really Excessive	3,34 s/d 4,17

Table 3.SEC Variable Criteria

Kriteria	Range of SEC
very good	≤ 85,853
good	85,853 s/d 108,094
poor	108,094 s/d 125,824
Very poor	≥ 125,824

Data Input Process

The ECI and SEC were used as the input for the Sugeno

FIS method. The input was conducted manually into the system. Both data were used as the required parameter to determine how much electricity the company used.

Sugeno Fuzzy Process

In using the FIS sugeno method required some process done, namely the formation of membership functions for input variables, formation of combination rules (fuzzyfikasi), and affirmation (defuzzyfikasi).

There were several steps in the Sugeno FIS method, namely membership function for the input variable, fuzzyfication and defuzzyfication.

1. Membership Function

   Based on the literature related to fuzzy membership function and the criteria of ECI and SEC in Table 2 and 3, the membership function for ECI variable was as follow (Figure 1).

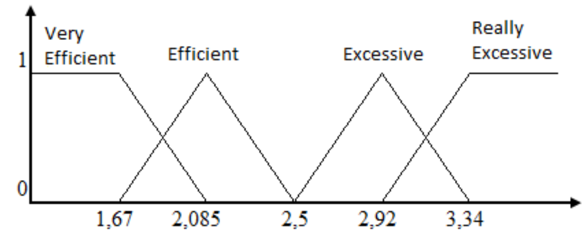

Fig 1. Membership Function of ECI Variable

Meanwhile, Figure 2 described the membership function for SEC variable.

Fig 2. Membership Function of SEC Variable

2. Combination and Weighting

   Table 4 described the combination used in this study.

Table 4. Combination for Electricity Consumption

No	Input		Output
	ECI	**SEC**	**Electricity Consumption**
1	Very efficient	Very good	Very efficient
2	Very efficient	good	efficient
3	Very efficient	poor	quite efficient
4	Very efficient	Very poor	quite Excessive
5	efficient	Very good	efficient
6	efficient	good	quite efficient
7	efficient	poor	quite Excessive
8	efficient	Very poor	Excessive
9	Excessive	Very good	quite efficient
10	Excessive	good	quite Excessive
11	Excessive	poor	Excessive
12	Excessive	Very poor	Excessive
13	Really Excessive	Very good	quite Excessive
14	Really Excessive	good	Excessive
15	Really Excessive	poor	Excessive
16	Really Excessive	Very poor	Really Excessive

3. Defuzzyfication

   To determine electricity consumption in the company, combination of the two variables as described in Table 4 was the requirement. The following formula was used to determine the output.

$$Z = \frac{\alpha_1(w_1)+\alpha_2(w_2)+\alpha_3(w_3)+...+\alpha_n(w_n)}{\alpha_1+\alpha_2+\alpha_3+...+\alpha_n}$$

Description:

Z = weighted average output and the constant (k),

α = α-predicate = minimum score from the nth fuzzyfication

W = Weights for each determination in the fuzzyfication

Based on the rules in Table 4 and the calculation of Z score after calculating the average weighting, it was confirmed the criteria described in Table 5 should be used to determine the electricity consumption

Table 5 Criteria for Electricity Consumption

Kriteria	**Range**
Very efficient	$Z \leq 0.25$
efficient	$0.25 < Z \leq 0.375$
quite efficient	$0.375 < Z \leq 0.5$
quite Excessive	$0.5 < Z \leq 0.625$
Really Excessive	$0.625 < Z \leq 0.875$
quite Excessive	$0.875 < Z \leq 1$

Result

This stage is the last stage, which displays the results of the processing of two input data into FIS sugeno method in the form of Z value and grouped according to criteria according to table 5. Manual calculation for sample training data from CV. Mahera 2015 in determining the use of electricity with two variables of ECI and SEC is as in table 6 below:

Table 6. Final Result of Training Data 2015 by Calculating Manual of FIS Sugeno Method

Month	ECI (kWh/ m^2)	SEC (kWh/ ton)	FIS Manual	Electricity Consumption
Jan	3,504	125,824	1	Really Excessive
Feb	4,574	110,997	0,875	Excessive
Mar	5,522	97,637	0,875	Excessive
Apr	1,880	107,033	0,4375	Quite Efficient
May	1,864	106,955	0,4375	Quite Efficient
Jun	1,249	85,853	0,25	Sangat Efficient
Jul	2,125	111,385	0,625	Quite Excessive
Aug	2,078	118,159	0,75	Excessive
Sep	1,419	97,652	0,375	Efficient
Oct	4,762	111,935	0,875	Excessive
Nov	3,793	122,810	0,9375	Really Excessive
Dec	1,438	100,892	0,375	Efficient

The last stage referred to describing the result of processing two inputs into the Sugeno FIS method. The result was Z score which was later classified based on the criteria described in Table 5. Table 6 described manual data analysis for electricity consumption in CV. Mahera in 2015 using two variables, ECI and SEC.
Table 6. The 2015 Training Data Result using Sugeno FIS Manual Calculation

System Implementation

Figure 3 described the real implementation in the matlab.

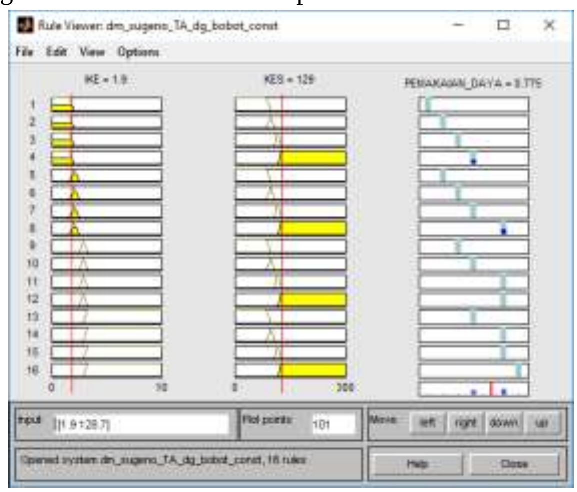

Fig 3. FIS Implementation using Matlab

Figure 3 showed that when user entered the ECI of 1.9 kWh/m2 and SEC of 129 kWh/ton, the electricity consumption (output) was 0.775, which was categorized as excessive. To replace the input, the user put a score on the input column between brackets ([ECI SEC]) and pressed the enter button. The program would automatically display the output. Another method was to shift the red line in the ECI and/or SEC variables in order to automatically change the electricity consumption score.
Analysis of the Test Result
Based on the testing using matlab in Table 7, the Sugeno FIS method was able to provide satisfying results or expected outcome.

IV. CONCLUSION

Based on the data related to the system implementation and testing obtained from the company between January, 2015 to April 2017, the average Energy Consumption Intensity (ECI) for January, 2016 to April 2017 is 1.949 kWh/m2; the score is categorized as efficient. On the other hand, the average of Specific Energy Consumption (SEC) from January, 2016 to April, 2017 is 126.108 kWh/ton; it is categorized as excessive.
Based on the average of ECI and SEC between January, 2016 and April, 2017, the consumption of electricity in CV. Mahera is categorized as excessive with the Sugeno FIS output 0.803. The Fuzzy logic with the zero-order Sugeno method is applicable for determining efficiency level of electricity consumption in a company. The efficiency level is shown based on the result of processing, analysis, and accuracy testing of the data obtained from the company.

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