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Statistical analysis using taguchi using method for wind turbine in ducting system

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ABSTRACT

Wind turbine is a device that converts kinetic energy of wind into electrical energy. Weak air pressure with an average of 2m/s to 4m/s makes wind turbine implementation in Malaysia becoming difficult and unrealistic. In order to produce a good power and torque, a quality air pressure is needed. Wind turbine performance depends on the incoming wind speed. Fluctuating and low quality air pressure are the significant challenges in wind turbine implementation. There are many types of mechanism and control but the production of output power is still considered low compared to the actual equipment. In a large building, Heat Ventilation Air Conditioning (HVAC) system is highly required to control the indoor temperature and consistent air pressure through ducting. The consistency of air pressure in ducting system make a drive for this research to proposed a wind turbine implementation in ducting system in order to produce electrical energy. In HVAC there are five parameters to be considered in order to identify the air pressure distribution in ducting system. These five parameters are input air pressure, ducting height, distance between blower to the pipe, total effective length and gap between trunk or run out. In this paper, an analysis of air pressure effect in a ducting system will be conducted via a development of air pressure prototype. Thousands of experiments are required with regards to a huge number of experiments to be considered. Spesifically a statistical analysis Taguchi Method is used to reduce a number of experiments. Without statistical analysis, 3125 experiments shall be conducted to identify the air pressure distribution in the ducting system. However, these huge number of experiments are reduced to only 25 experiment by using Taguchi method based on the function of L25 in array orthogonal.

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1. INTRODUCTION

Fossil fuels had been used up to 80% to fulfil the requirement of world energy and it slowly decreasing day by day [1]. Renewable energy should be developed widely in all countries in this world. Due to climate problem and fossil based resources are limited, demand on renewable energy increases time by time. In Denmark electrical energy is produced from wind turbine and will be increased up to 50% or future development [2]. Renewable energy is converting natural phenomenon into electrical energy. There are many type of renewable energy around the earth such as from sun [3], wind [4], biomass [5] and biogas [6]. The performance of renewable energy are different in every country. Netherland is one of the country in this world which utilize s the wind energy as their resources. These are three successive market period: Monopoly power (1989-1995), Interbellum (1996-1997) and Free market (1998-2002) [7]. Many countries has developed and perform continuous research to produce electrical energy from natural resources. In Malaysia for example, Sustainable Energy Development Authority (SEDA) has listed only four types of energy which are recognized as national resources and surprisingly wind is not in the list [8]. These is due to the factors such as geographical, weak air pressure and low power production by wind energy makes wind turbine implementation in Malaysia becoming almost impossible. According to [9] only in Mersing and Kuala Terengganu be the two potential locations that would achieve the highest output power via wind turbine implementation. However it still depends on the Northeast monsoon and still be useful in few months duration. Other factor such as inconsistency of air outdoor air distribution, the setting of wind turbine height and installation near to the sea might add up the difficulty of wind turbine implementation in Malaysia. Figure 1 shows the wind distribution at Malaysia and it clearly shows the performance of natural wind are in average speed of 2m/s.

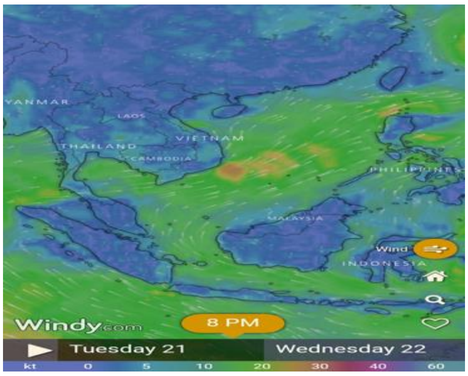


Figure 1. Windy software analysis for air pressure at Malaysia

There are many strategies had been explored in order to produce a good output power by using wind turbine. In a research by [25], the optimization using artificial intelligent algorithm had been use to improve the designing, planning and control the energy system in renewable energy. Some analysis is still using a traditional method, modern and mix method involve in order to optimize the energy system. However until now with many approaches in optimization, wind turbine will not be successful anywhere with a low air pressure. In this research the potential of Heat Ventilation and Air Conditioning (HVAC) system as an energy source to wind turbine system is explored. The existing air pressure inside HVAC will be used by installing an appropriate wind turbine inside the HVAC system. Besides controlling the temperature and indoor air distribution through the ducting system [10], HVAC system is known to improve the air quality. In order to get the best air distribution system, a study on mathematical model is important to ensure a balanced air pressure delivered in the ducting system [11]. Building designer has increased the demand on the standard of building structure which implement HVAC system. There are many software and tools available to be used but the complexity of the system becomes the biggest problem in ensuring that the performance of the design can be achieved [12]. Research in [13] reveals the analysis on the noise in HVAC is straight forward whereas the analysis on the approach system was complicated and difficult to identified. According to [14], the application of computer are strictly for Computer Aid Drafting (CAD) and steady state calculation. The complexity of design was developed by researcher and scientists based on the real usage in practice. They are referring to the real world complexity which requires powerful and accurate model. In other hand, designers are more interested with simple and straight forward tools to design a HVAC system [15]. Researcher believed by using tools and technique, it can improve 70% of design [16]-[17]. Lack of building information makes the optimal design can't be achieved [18]-[19]. There are two main information in designing HVAC in building which are development of software dedicated towards integrating software and thermal simulation. All the data was set in database. However not all community utilize all the information so that makes the system integration failed to be followed [14]. In order to design a ducting in HVAC system, there are many reference and standard to be followed. The standard depends on the recognize board for approval purpose such as Japanese Industrial Standard (JIS) [20]. In developing air distribution system, there is no reference for multiple air distribution system. The design of ducting system was developed based on building and specific requirement such as the design for duct will become small until end of trunk or runout. The experiment will focus on the specific application before implementing the wind turbine in ducting system. Hence this analysis will become a reference for air distribution system in ducting system.

The analysis used a statistical analysis to identify most significant factor that would influence the air distribution system in ducting system. The main reason to use statistical analysis is to reduce the number of experiment, time and cost. Taguchi method was used in many application to analyse the significant factor in any experiment [21]. In a research by [22], Taguchi method was used to analyse and predict the drilling process and an effective method for the drilling, induced delimitation factor (error within 8%). In a research by [24], Taguchi method had been use to optimize the laser welding. Based on the result shows that the optimization in tension stress of 169MPa, 2.5 times larger from the original setting. In a research by [23], Taguchi method was used to identify the optimum factor and level to obtain optimum multiple-performance characteristics of a diesel engine run with different low-percentage thumba biodiesel diesel blends. The result shows by using L9 orthogonal array produces maximum multiple performance of a dieselengine with minimum multiple emissions from the engine. This paper will use a statistical analysis to identify the air pressure in ducting system. This analysis is very important to ensure the performance of air pressure in HVAC system.

2. RESEARCH METHOD

Prototype for ducting system was developed as shown in Figure 2. The design was developed with 4 block of ducting. The prototype was designed separately and each block can move and make a distance from each other. The purpose is to explore the losses and air distribution while delivering the air pressure.

Each block will connected with an anemometer. The anemometer can read up to 32m/s of air velocity. Figure 3 displays the hardware of experiment setup which is used and to analyse the performance of wind flow inside the ducting system by using Labview software. Note that, the graphic user interface (GUI) for system real time analysis is developed in [23].

Table 1 shows the parameters used to analyse the distribution of wind flow inside the ducting. Capital letter of A represent the input pressure from the blower in meter per second (m/s). Then, capital letter of B represents the height between the compartment, C represents the distance of pipe from the blower, D represents total effective length on the centre height of the compartment and finally, E represents the gap between the ducting compartment. The locations of these five parameters are labelled in Figure 4 and Figure 5.Parameters represented by B, C, D and E are expressed in inches.

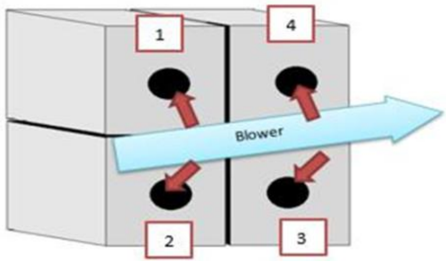


Figure 2. The illustration of ducting system prototype

Figure 3. Front view of ducting

Table 1. Five Parameter Considered for Wind Analysis

Parameter	A	B	C	D	E
	Input Pressure	Height	Distance Blower	Total Effective Length (TEL)	Gap
Level	0.5	0’	0.5’	0.5	0’
	2.5	0.5’	1.0’	1.0	1’
	5	1.0’	1.5’	1.5	2’
	10	1.5’	2.0’	2.0	3’
	15	2.0’	2.5’	2.5	4’

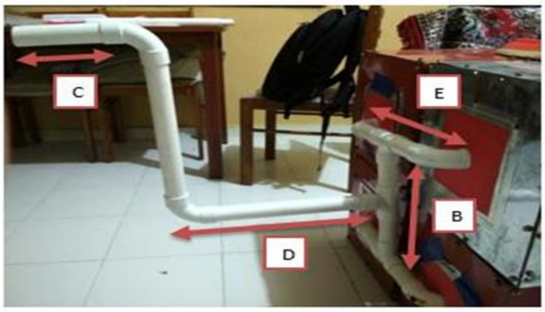


Figure 4. Parameter observed in the analysis

Figure 5. Experiment

The observed indicator is the rate of air flow inside the ducting system without obstacle in the ducting system. Based on the array orthogonal, the numbers of experiments have been reduced to 25 experiment. Purpose of using statistical Taguchi analysis is to reduce cost, time and waste in order to conduct all the experiments in this project. Every parameter in this experiment was set with 5 different levels.

Table 2. Orthogonal Array of Taguchi

	Parameter				
No. of Exp	A	B	C	D	E
1	1	1	1	1	1
2	1	2	2	2	2
3	1	3	3	3	3
4	1	4	4	4	4
5	1	5	5	5	5
6	2	1	2	3	4
7	2	2	3	4	5
8	2	3	4	5	1
9	2	4	5	1	2
10	2	5	1	2	3
11	3	1	3	5	2
12	3	2	4	1	3
13	3	3	5	2	4
14	3	4	1	3	5
15	3	5	2	4	1
16	4	1	4	2	5
17	4	2	5	3	1
18	4	3	1	4	2
19	4	4	2	5	3
20	4	5	3	1	4
21	5	1	5	4	3
22	5	2	1	5	4
23	5	3	2	1	5
24	5	4	3	2	1
25	5	5	4	3	2

3. RESULTS AND DISCUSSION

Table 3 shows the result of experiment. Based on the experiment in previous section, there are four output from block 1, block 2, block 3 and block 4. Every block was tested without obstacle where the purpose of study to analyse the air distribution in ducting system. Data was taken for two times and been averaged out. y is a total output from all average result in the ducting. Total data for 25 experiment in column y is 107.39 and average for 25 experiment is 4.30. Table 4 shows the result on the average effect to each factor and level in parameters. Main effect is an average of the result (Table 2) from the each factor in the same level.

Table 3. Result of Experiment

										Anemometer								
							1			2			3			4		
No.	A	B	C	D	E	Exp1	Ex2	Avg	Exp1	Exp2	Avg	Exp1	Exp2	Avg	Exp1	Exp2	y	
1	1	1	1	1	1	1.4	1.55	1.48	3.25	3.4	3.33	1.85	1.2	1.52	0.2	0.1	0.15	6.48
2	1	2	2	2	2	1.85	1.4	1.63	3.25	4.5	3.88	0.6	0.4	0.5	0.15	0.1	0.13	6.14
3	1	3	3	3	3	0.4	0.25	0.33	1.1	1.3	1.2	0.75	0.25	0.5	0.1	0.45	0.28	2.31
4	1	4	4	4	4	0.15	0.05	0.1	0.75	0.9	0.83	0.4	0.3	0.35	0.05	0	0.03	1.31
5	1	5	5	5	5	0.05	0.2	0.13	0.75	0.45	0.6	0.25	0.45	0.35	0	0	0	1.08
6	2	1	2	3	4	0.8	0.7	0.75	0.9	0.7	0.8	0.4	0.3	0.35	0.2	0.25	0.23	2.13
7	2	2	3	4	5	0.7	0.625	0.66	0.5	0.25	0.38	0.25	0.1	0.18	0.1	0.1	0.1	1.32
8	2	3	4	5	1	0.8	0.55	0.68	0.4	0.6	0.5	0.25	0.2	0.23	0.45	0.2	0.33	1.74
9	2	4	5	1	2	1.4	0.85	1.13	3.15	2.7	2.93	0.55	0.65	0.6	0.55	0.4	0.48	5.14
10	2	5	1	2	3	1.55	1.1	1.33	2.1	1.85	1.32	0.9	0.8	0.85	0.55	0.45	0.5	4.00
11	3	1	3	5	2	0.45	0.45	0.45	3.75	4	3.88	1.35	1.15	1.25	0.15	0.35	0.25	4.15
12	3	2	4	1	3	0.25	0.15	0.20	1.7	1.55	1.63	0.7	0.3	0.5	0.2	0.05	0.13	2.46
13	3	3	5	2	4	0.9	1	0.95	1.4	1.35	1.38	0.3	0.9	0.6	0.2	0.15	0.18	3.11
14	3	4	1	3	5	4.5	5.5	5.00	1.4	1.15	1.28	0.25	0.3	0.28	0.35	0.3	0.33	6.89
15	3	5	2	4	1	6.75	5.7	6.23	1.1	0.85	0.98	0.15	0.2	0.18	0.35	0.2	0.28	7.67
16	4	1	4	2	5	0.35	0.75	0.55	1.7	1.4	1.55	0.95	0.55	0.75	0.3	0.4	0.35	3.2
17	4	2	5	3	1	0.95	0.8	0.88	0.65	0.55	0.6	1.6	1.9	1.75	0.7	0.5	0.6	3.83
18	4	3	1	4	2	1.35	1.1	1.23	1.25	0.95	1.1	0.95	0.7	0.83	0.75	0.4	0.53	3.69
19	4	4	2	5	3	2.6	2.95	2.78	1.6	1.9	1.75	0.25	0.4	0.33	1.05	0.95	1.00	5.86
20	4	5	3	1	4	1.9	1.65	1.78	2.25	2.05	2.15	0.15	0.1	0.13	1.25	1.05	1.15	5.68
21	5	1	5	4	3	1.95	1.7	1.83	4	3.6	3.8	2.55	2.3	2.43	0.1	0	0.05	8.11
22	5	2	1	5	4	1.4	1.35	1.38	0.45	0.45	0.45	1.35	0.95	1.15	0.35	0.65	0.5	3.48
23	5	3	2	1	5	0.9	1.25	1.08	0.65	0.45	0.55	1.9	1.4	1.65	0.45	0.45	0.45	3.73
24	5	4	3	2	1	1.1	1.6	1.35	6.5	5.5	6.00	1.35	1.1	1.23	0.25	0.35	0.3	8.88
25	5	5	4	3	2	0.95	0.8	0.88	3.7	4.05	3.88	0.75	0.85	0.80	0.15	0.05	0.1	8.48

Table 4. Result of Main Effect

Factor	Level	(Level in parameter)	Main Effect
	1	17.32	3.46
	2	14.33	2.87
	3	24.28	4.86
	4	22.26	4.45
A	5	32.68	6.54
	1	24.07	4.81
	2	17.23	3.45
	3	14.58	2.92
	4	28.08	5.62
B	5	26.91	5.38
	1	24.54	4.91
	2	25.53	5.11
	3	22.34	4.47
	4	17.19	3.44
C	5	21.27	4.25
	1	23.49	4.70
	2	25.33	5.07
	3	12.31	2.46
	4	22.1	4.42
D	5	16.31	3.26
	1	28.6	5.72
	2	27.9	5.58
	3	22.74	4.55
	4	15.71	8.94
E	5	16.22	3.24
Total			114.48

Table 5 shows the result on the factor contribution. Factor contribution is the highest result in the column main effect for each factor. For example the highest factor contribution for factor a is 6.54. This result will be deducted from the average result of experiment. The total result of experiment in table is 107.39 and the average result in experiment is 4.30. Based on the result the highest contributing factor is factor E, followed with factor A, factor B, factor C and factor D. Figure 7 shows the result on the graph for factor contribution versus parameter.

$$\text{Factor Contribution} = \text{Highest Result} - \text{Average} \tag{1}$$

Average Result = Total Result/No. of Exp (2)

Table 5. Factor Contribution

Factor	The Highest Value Contribute	Factor Contribution
A	6.54	2.24
B	5.62	1.32
C	5.11	0.81
D	5.07	0.77
E	8.94	4.64

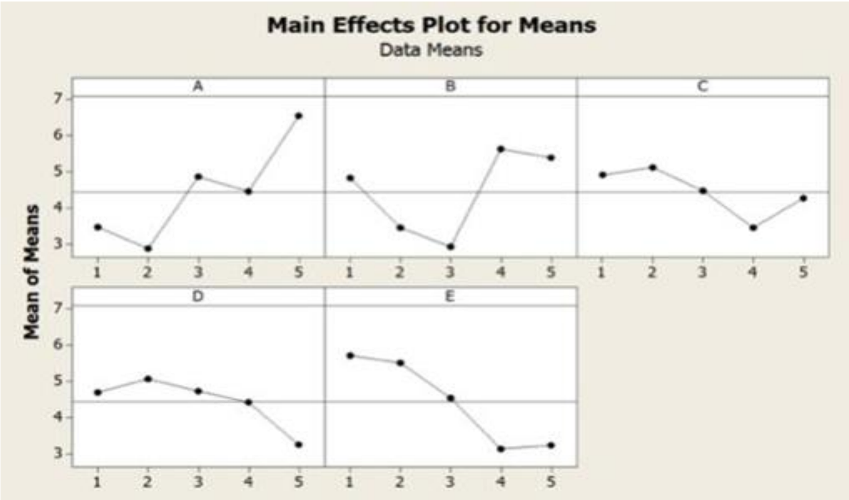


Figure 6. Main effect plot

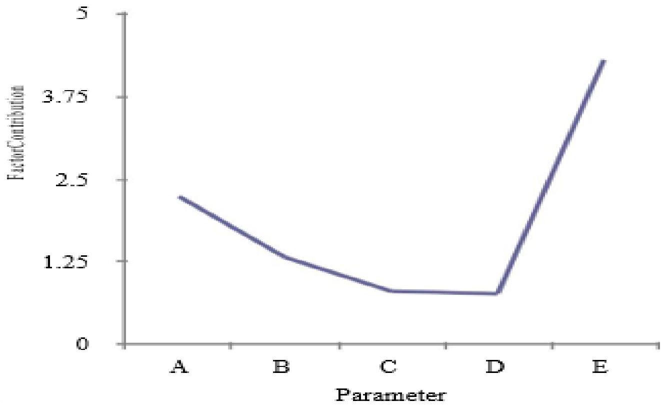


Figure 7. Factor Contribution Versus Parameter

Table 6 shows the result for signal noise ration (S/N ratio). Calculation for the S/N ratio is as shown in (3). The MSD value is calculated as in (4).

S/N = -10log10 (MSD) (3)

MSD = (1/y1+ 1/y2)2 / 2 (4)

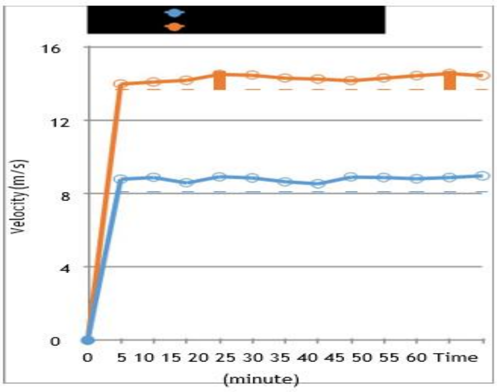
Table 6. Result for S/N Ration

Experiment	Output	MSD	S/N Ratio
1	6.48	0.012	19.208
2	6.14	0.013	18.861
3	2.31	0.093	10.315
4	1.31	0.29	5.376
5	1.08	0.428	3.685
6	2.13	0.110	9.586
7	1.32	0.286	5.436
8	1.74	0.165	7.825
9	5.14	0.019	17.212
10	4.00	0.031	15.086
11	4.15	0.029	15.376
12	2.46	0.083	10.809
13	3.11	0.052	12.839
14	6.89	0.011	19.586
15	7.67	0.008	20.969
16	3.20	0.049	13.098
17	3.83	0.034	14.685
18	3.69	0.036	14.436
19	5.86	0.014	18.538
20	5.68	0.015	18.239
21	8.11	0.008	20.969
22	3.48	0.041	13.872
23	3,73	0.036	14.436
24	8.88	0.006	22.218
25	8.48	0.007	21.549

Figure 8 shows the result on the signal ratio versus number of experiment. Based on the result the highest result of the experiment was experiment number 24th with the algorithm A5B4C3D2E1. However based on the Taguchi analysis the highest result based on the statistical analysis the optimum result can be achieved with algorithm A5B4C2D2E4.Based on the highest result in main factor for each factor, the highest result for a parameter is A5B4C2D2E4. The expected is 14.08m/s compared to the 24th experiment with 8.88m/s as shown in (5). In order to confirm the result, confirmation experiment was conducted to identified the performance of the algorithm approach by Taguchi method. Figure 9 shows the result on the confirmation and the the performance had been achieved.

$$Yopt = T + (A5 - T) + (B4 - T) + (C2 - T) + (D2 - T) + (E4T) \quad (5)$$

Figure 8. S/N Ration versus No. of Experiment



Fugure 9. Confirmation Experiment

4. CONCLUSION

In conclusion, analysis of the result shows that the most significant factor in this experiment is factor E, followed by factorA, factor B, factor C and factor D. Taguchi analysis help to identified most significant parameter influence in experiment. Without using statistical analysis total output air pressure can be achieved 59.2% but by using statistical analysis the output achieved up to 92% of efficiency. Based on this, clearly shows statistical analysis can increased the system in robust analysis and reduce a time to identify significant factor influence in the experiment setup.

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