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Quality Improvement of Instrument Transformer Using Taguchi Experiment Method in PT. XYZ

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Abstract— **Up to this year, PT. XYZ has been experienced of increasing sales of instrument transformer products, along with increasing consumer demand. Quality is the most important thing in the manufacturing product. But on the production floor of PT. XYZ faces quality problems. Based on the 2018 production report from January to December the number of defective products is more than 2 %. The high defective products indicate that there needs to be an improvement in the production process as a form of effort to improve quality on an ongoing basis. However, to achieve these objectives the company must know which control factors have an effect on improving the quality of the product. This research is intended to assist companies in solving problems of multiresponse cases that occur in the case of instrumentation transformer defect products, it will be analyzed using Taguchi Experiment combined with the PCR- TOPSIS method to improve product quality. Based on the results of this research, the results obtained that using the PCR-TOPSIS method optimum conditions can be achieved in the oven temperature control factor 110°C, oven time 240 minutes, mixing temperature 60°C, mixing time 130 minutes, clamping pressure 3 bars, and time clamping 20 minutes. By using the optimum treatment settings can be achieved quality improvement in each response with the characteristics of the quality is larger is better, where the increase in power frequency response increases by 11.11% and the response of partial discharge increases by 39.17%.**

Keywords— **Transformer Instrument, Quality, Taguchi Experiment, PCR-TOPSIS, Manufacturing Process.**

I. INTRODUCTION

THE PROGRESS of the era of an industry that continue to grow need electricity consumption, together with an increase in electrification, economic growth, and a change in the lives of the community. In addition, the number of people in indonesia continue to grow, this might impact on as a house with the increase in the number of office buildings to industrial center and shopping centers that can affect the level demand of electrical power in indonesia, the number of demand of electrical power to be supported by the system electric networks in which large. In addition to demand of electrical power, also network system system for the distribution of electricity to integrate the electricity from power plants to the consumer the end or the community, to help integration of electric system in indonesia, required an electrical device that reliable.

Pt. XYZ is one of several manufacturing companies in indonesia that moves in the field of electricity that produces electrical products in the form of transformer and electrical utility that can give one of solutions in meet an electricity network and distribution of indonesia. The product that produced by the company has some kind of of products including power transformer, transformer distribution and instrument transformer. On the other hand during the production process in pt. Xyz still have a problem a quality on one of their products that is instrument transformer. The problems quality of occurring could result in losses for the company, the loss came after a raw materials by replacing material, production time, working years to employees, as well as other resources wasted it will be useless, the loss was could reduce company profit. Instrument transformer is illustrated in figure 1. And in table 1 show production report transformer instrument in 2018.

Based on the data production report in 2018 from january to december table shown 1. Trafo instrumentation products, with the total 8.300 units are located unit 166 products fail. The percentage of failure the highest 3,43% in june and the lowest of 0,17% in july, while the percentage average failure for one year which is 2,00%.

The causes of the decline quality is because variability higher than a product produced. The process of producing the manufacture of a transformer instrumentation consisting of 3 stage is active part processes, casting processes, and the final processes. During the production process a defect that is most common happened on the outcome of the process of casting processes. Results of casting processes influenced by five factors control that is the temperature of an oven, time an oven, mixing temperature, time mixing, clamping pressure, and time clamping.

To increase the reliability of the system that is needed optimation in the response of power frequency and partial discharge. In general, the proper setting this control was based on engineer knowledge and operators who have experienced. Hence, this research methods necessary solution to overcome the problem occurs in the production process facing, company with the calculation of statistics to know the right combination of proper multi-respon experiment in the case [1].

Taguchi method is an efficient approach using planning experiments to produce a combination of factors or levels that can be controlled by taking into account the lowest price but still needs and expectations. However, Taguchi method can only be used to solve a single problem that is addressed. So the Process Capability Ratio (PCR) theory is used to see if

Table 1.
The Production Report Of Instrument Transformer in 2018

No	Month	Passed Product	Defect Product	Percentage of Defect Products (%)
1	January	465	10	2.15
2	February	681	5	0.73
3	March	970	29	2.99
4	April	605	17	2.81
5	May	749	19	2.54
6	June	534	15	2.81
7	July	593	1	0.17
8	August	714	5	0.70
9	September	637	20	3.14
10	October	875	30	3.43
11	November	685	7	1.02
12	December	626	8	1.28
	Total	8134	166	
	Production Total	8300		

Table 2.
Level of Control Factor

No	Control Factor	Symbol	Level 1	Level 2	Level 3
1	Oven Temperature (°C)	A	110	120	130
2	Oven Time (minute)	B	240	360	480
3	Mixing Temperature (°C)	C	40	50	60
4	Mixing Time (minute)	D	70	100	130
5	Clamping Pressure (bar)	E	2.5	3	3.5
6	Clamping Time (minute)	F	10	15	20

there is still a process within the specified tolerance limits, and Technique for Sequencing Performance with Similarities to the Ideal Solution rating (TOPSIS) so that it can determine the optimal multiresponse combination [2]. So that it can be seen the factor/level combination for each response and factor/level that most influences response.

II. METHOD

A. Taguchi Method

Taguchi method focuses on achieving certain targets and reducing variations in a product or process by using factor design. If the number of factors that are thought to affect a process or the results of the process by using Taguchi method, it can be concluded which factor is only noise.

Taguchi method is formed with a system of design to reduce variability in a process or product, as well as a guide for obtaining results with optimal settings. Taguchi method is an efficient approach that uses experimental planning to produce a combination of factors or levels that can be controlled by paying attention to the lowest price while still meeting consumer demand [2]. Three stages in applying Taguchi method to optimize a product or process are [2]:

a. System design. System design is used to select a good production method in completing the production process.
b. Design control faktor. Meanwhile, design control factor is used to find a factor or level that can be controlled and minimize the influence of the noise factor.
c. Tolerance design. Tolerance design is the main effect on product quality in terms of quality loss and cost-effectiveness of production.

Experiment design in Taguchi method is based on orthogonal arrays. Orthogonal arrays are used to determine minimum and efficient number of trials but still achieve the optimum setting from the control parameters. The name order shows how many rows and columns you have, as well as the number of levels for each column.

The use of Taguchi method in experimental design is based on the Orthogonal Array (OA) in order to obtain the maximum amount of information with minimal experiments, besides that it can also analyze experimental data based on the Signal to Noise Ratio (SN Ratio) [3] . Orthogonal Array (OA) is a matrix whose elements are composed of rows and columns. Rows are the level combinations of factors in the experiment. Each column is a factor that can be changed in the experiment. Taguchi philosophy consists of three concepts [4], is the quality that must be designed into the product and not just checking it, the best quality is achieved by minimizing the deviation from the target. Products must be designed to be robust against uncontrollable environmental factors, the cost of quality must be measured as a function of deviation from a certain standard and losses must be measured across the entire system.

Selection of the type of Orthogonal Array (OA) used in the experiment depends on the total number of degrees of freedom. Determination of the total degrees of freedom is based on three things: the number of process variables (control factors), the interaction factor between the observed factors and the number of levels of the observed factors. Orthogonal Array for three levels:

Analysis stage of Taguchi method uses Signal to Noise Ratio (SN Ratio). Signal to Noise Ratio is a way to see the characteristics of the distribution and the influence of these characteristics in each experiment [5]. SN Ratio value is obtained from the transformation of several data repetitions so that the value represents the quality of the variation presentation. Calculation process used to determine the value of SN Ratio [6], is:

In this step, ηi (S/N ratio for response to j in experiment i where i = 1,2,3,…,m dan j = 1,2,3,…,n) calculated by following three formulas.

Figure 1. Instrument Transformer.

Table 3.
Design of Taguchi Experiment

Run	Control Factor					
	A	B	C	D	E	F
1	110	240	40	70	2.5	10
2	110	240	40	70	3	15
3	110	240	40	70	3.5	20
4	110	360	50	100	2.5	10
5	110	360	50	100	3	15
6	110	360	50	100	3.5	20
7	110	480	60	130	2.5	10
8	110	480	60	130	3	15
9	110	480	60	130	3.5	20
10	120	240	50	130	2.5	15
11	120	240	50	130	3	20
12	120	240	50	130	3.5	10
13	120	360	60	70	2.5	15
14	120	360	60	70	3	20
15	120	360	60	70	3.5	10
16	120	480	40	100	2.5	15
17	120	480	40	100	3	20
18	120	480	40	100	3.5	10
19	130	240	60	100	2.5	20
20	130	240	60	100	3	10
21	130	240	60	100	3.5	15
22	130	360	40	130	2.5	20
23	130	360	40	130	3	10
24	130	360	40	130	3.5	15
25	130	480	50	70	2.5	20
26	130	480	50	70	3	10
27	130	480	50	70	3.5	15

For response characteristic of smaller the better, then:

$$\eta_j^i = -10\log_{10}\left[\frac{1}{l}\sum_{k=1}^{l}(y_{jk}^i)^2\right], 0 \le y_{jk}^i \le \infty$$

For response characteristic of larger is better, then:

$$\eta_j^i = -10\log_{10}\left[\frac{1}{l}\sum_{k=1}^{l}\frac{1}{(y_{jk}^i)^2}\right], 0 \le y_{jk}^i \le \infty$$

For response characteristic of nominal the best, then:

$$\eta_j^i = -10\log_{10}\left[\frac{(\bar{y}_j^i)^2}{(s_j^i)^2}\right], 0 \le y_{jk}^i \le \infty$$

where,

yi: Observed data for response to-i in experiment to-i and k repetition.

$\bar{yi}$: Data mean that observed for response to-j in experiment to-i

($S\ j$): Variations in observed data for response to-j in experiment to-i, i=1,2,…m and k=1,2,…,l.

B. Process Capability Ratio (PCR)

Process capability is used to see whether a process or product is within tolerance limits [2]. Process capability analysis can illustrate computation of process changes related to product specifications, and help in reducing variance in development and manufacturing processes [7]. A process can be said to be good, if it is between upper and lower limits. If target is in the

± 3s area, it is likely that the product produced is good. However, if the target is outside 3s, it can be said that the product produced is not good. Process capability index is used to calculate the ratio between the desired dimensions and the best results of a product produced. To obtain PCR-SN Ratio results, it is necessary to transform the SN Ratio value of each response variable [2].

Step used in conducting optimize with PCR-TOPSIS begins by counting S/N ratio.

Quality contribution that maximum for the response to-j in experiment to-i shows Ci (PCR-S/N ratio in response to-j for experiment to-i) with the following calculations.

$$C_j^i = \frac{\eta_j^i - \bar{x}_{\eta_j}}{3 s_{\eta_j}}$$

Sample mean to S/N ratio in response to-j.

$$\bar{x}_{\eta_j} = \frac{\sum_{i=1}^{m}\eta_j^i}{m-1}$$

Table 4.
Response Result of Experiment dan S/N Ratio

Run	Experiment Result		S/N	Partial Discharge
	Power Frequency	Partial Discharge	Power Frequency	
1	18	13	25.1055	22.2789
2	17	14	24.609	22.9226
3	15	18	23.5218	25.1055
4	16	16	24.0824	24.0824
5	17	10	24.609	20
6	9	11	19.0849	20.8279
7	16	2	24.0824	6.0206
8	20	16	26.0206	24.0824
9	7	18	16.902	25.1055
10	12	3	21.5836	9.5424
11	19	20	25.5751	26.0206
12	3	4	9.5424	12.0412
13	19	3	25.5751	9.5424
14	20	17	26.0206	24.609
15	8	16	18.0618	24.0824
16	19	8	25.5751	18.0618
17	18	17	25.1055	24.609
18	7	8	16.902	18.0618
19	18	10	25.1055	20
20	17	15	24.609	23.5218
21	6	16	15.563	24.0824
22	14	5	22.9226	13.9794
23	11	1	20.8279	0
24	5	11	13.9794	20.8279
25	4	2	12.0412	6.0206
26	3	1	9.5424	0
27	4	8	12.0412	18.0618

Table 5.
Result of PCR-SNR

No.	*PCR-SNR*	*Partial Discharge*
	Power Frequency	
1	0.2184	0.1546
2	0.1884	0.1816
3	0.1229	0.2732
4	0.1567	0.2303
5	0.1884	0.0589
6	-0.1447	0.0937
7	0.1567	-0.5278
8	0.2735	0.2303
9	-0.2763	0.2732
10	0.006	-0.38
11	0.2467	0.3116
12	-0.7201	-0.2751
13	0.2467	-0.38
14	0.2735	0.2524
15	-0.2064	0.2303
16	0.2467	-0.0224
17	0.2184	0.2524
18	-0.2763	-0.0224
19	0.2184	0.0589
20	0.1884	0.2067
21	-0.357	0.2303
22	0.0867	-0.1938
23	-0.0396	-0.7805
24	-0.4525	0.0937
25	-0.5694	-0.5278
26	-0.7201	-0.7805
27	-0.5694	-0.0224

Sample standard deviation for S/N ratio in response to-j.

$$s_{\eta_j} = \sqrt{\frac{\sum_{i=1} (\eta_j^* - x_{\eta_j^i})}{m-1}}$$

C. The Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS)

Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) based on a method of multiple criteria to identify limited problems solution of alternatives available.

Table 5.
Result of PCR-SNR

No.	PCR TOPSIS
1	0.8884
2	0.8949
3	0.8967
4	0.9038
5	0.8227
6	0.6894
7	0.5184
8	0.9457
9	0.6747
10	0.5279
11	0.9819
12	0.3046
13	0.6019
14	0.9603
15	0.6996
16	0.7857
17	0.9452
18	0.5772
19	0.8296
20	0.9085
21	0.6281
22	0.6493
23	0.3746
24	0.5467
25	0.1983
26	0
27	0.4602

The basic principle of TOPSIS is selection of alternative must have distance smallest size is for ideal of greatest positive and distance to ideal of negative Ideal solution positive is best grades who accomplished in the any attribute. While solution ideal negative is the worst of any attribute .

Next step is to calculate TOPSIS from results of PCR-S/N ratio.

$$\varsigma^i = \frac{d^{i-}}{d^{i+}+d^{i-}}$$

with,

$$d^{i+} = \sqrt{\sum_{j=1}^{n} (C^i_j - C^+_j)^2}$$

$$d^{i-} = \sqrt{\sum_{j=1}^{n} (C^i_j - C^-_j)^2}$$

where,

d^{i+} for i=1,…,m : Distance of experiment to-i from ideal solution

d^{i-} for i=1,…,m : Distance of experiment to-i from ideal solution

$C^+_j = \max \{C^i_j$, for $i = 1,2,\ldots,m\}$, $\forall C^i_j$ $(i = 1,2,\ldots,m, j = 1,2,\ldots,n)$

$C^-_j = \min \{C^i_j$, for $i = 1,2,\ldots,m\}$, $\forall C^i_j$ $(i = 1,2,\ldots,m, j = 1,2,\ldots,n)$

D. Steps of Taguchi Multirespon PCR-TOPSIS Method

To get the optimization results of Taguchi Method with the PCR-TOPSIS approach can be achieved through the following steps [2]:

Table 7.
ANOVA Calculate Result from Result of PCR-TOPSIS

Source	*DF*	*SS*	*SS'*	*MS*	*F-Value*	*P-Value*	*ρ*
A	2	0.4033	0.3437	0.20167	6.77	0.009	20.613
B	2	0.1764	0.1168	0.08818	2.96	0.085	7.005
C	2	0.2356	0.176	0.11778	3.95	0.044	10.555
D	2	0.1733	0.1137	0.08665	2.91	0.088	6.819
E	2	0.107	0.0474	0.05348	1.79	0.202	2.843
F	2	0.1546	0.095	0.07732	2.59	0.11	5.697
Error	14	0.4173		0.0298			
Total	26	1.6674					

Table 8.
Optimum Result of Each Control Factor/Level

Level	A	B	C	D	E	F
1	**0.804**	**0.762**	0.729	0.622	0.656	0.575
2	0.709	0.694	0.543	**0.788**	**0.759**	0.690
3	0.511	0.567	**0.752**	0.614	0.609	**0.758**
Delta	0.293	0.195	0.209	0.174	0.151	0.183
Rank	1	3	2	5	6	4

Table 9.
Optimum Prediction Value for Each Responses

	Power Frequency	**Partial Discharge**
Mean	23,7778	23,5926
SNR	30,8913	38,8694

Table 10.
Result of Confirmation Experiment

No	**Response**	**Characteristic of Quality**	**Initial Condition**	**Optimum Condition**		**Improvement**
				Prediction	Experiment	
1	*Power Frequency*	*Larger is better*	18	23.7778	20	Increase 11.11%
2	*Partial Discharge*	*Larger is better*	14.3703	23.5926	20	Increase 39.17%

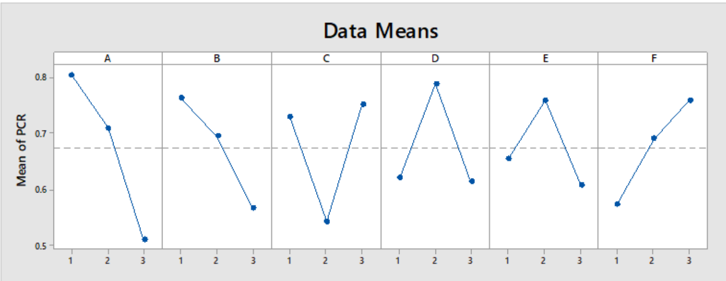

Figure 2. Plot Effect of Each Control Factor.

a. Calculating Signal to Noise (SN Ratio).
b. Calculating PCR-SN Ratio for each of the calculation experiments (PCR-SN Ratio for j responses and i experiments).
c. Calculating TOPSIS from the PCR-SN Ratio results.
d. Testing ANOVA assumption from the TOPSIS-SN Ratio results.
e. Creating ANOVA table from the TOPSIS PCR-SN Ratio results. The ANOVA table will calculate the number of squares, the average number of squares, and the f-count of each independent variable which is the controlled factor. ANOVA table is used to determine the effect of factors and the interaction of one response from the TOPSIS PCR-SN Ratio results.
f. Testing influence of factors againts responses.
g. Determine the optimal conditions for the contribution of the factor combination and the level of the factor significance of the multi-response.
h. Calculating optimal value conditions for each response.

III. RESULT AND DISCUSSION

A. Calculate of Signal Noise to Ratio (SN Ratio)

SN Ratio value is obtained from transformation of several data repetitions so that the value represents quality of variation presentation. Taguchi method is used to maximize the SN Ratio value but minimize variance value. So that two response variables use larger is better SN Ratio for calculation characteristics.

B. Process Capability Ratio-Signal Noise to Ratio (PCR-SN Ratio)

Process capability is used to determine whether a process falls between top and bottom specifications. A process is said to be good if it is within ± 3 standard deviations on the average. The PCR-SN Ratio value is obtained from the transformation of the SN Ratio value for each response variable. The calculation results are shown in Table 5.

C. PCR-TOPSIS

To determine the nearest distance with a solution of positive and negative ideal with a solution the farthest, so multi criteria TOPSIS used method of decision making. TOPSIS value can be used as a reference to determine the optimal level/factors. Results of calculated TOPSIS is on Table 6.

D. Analysis of Variance (ANOVA)

Results of the PCR-TOPSIS calculations obtained were then carried out by analysis of variance (ANOVA) which was used to determine the effect of factors and interactions on one response represented by PCR-TOPSIS value for the two previous responses. The results of the ANOVA analysis can be seen in Table 7.

Based on Table 7, it can be explained that at level of $\alpha = 0.05$, all major factors and interaction factors have a significant influence, it can be seen at p-value for all main factors $> \alpha = 0.05$.

E. Determination of Optimum Conditions

To obtain optimum conditions, level chosen is level that gives largest average SNR value for each response. Average SNR value of each level for each response can be seen on Figure 2.

Based on Figure 1 and Table 8, it can be seen that optimum conditions for quality can be achieved at a combination of levels A1 B1 C3 D2 E2 and F3. Table 8 also explains that factor A (oven temperature) has most influence on response, this can be seen from the biggest delta value from ranks first. While E factor (clamping pressure) is smallest factor that has an effect on response, this can be seen from the smallest delta value from the most recent ranking.

To get the predicted value of each response using the optimal level design A1 B1 C3 D2 E2 F3.

Based on Table 9, it can be seen that predictive value of mean of power frequency response is 23,7778 with SNR prediction of 30,8913. While predictive value of mean of partial discharge response is 23,5926 with a SNR prediction of 38,8694.

F. Confirmation Experiment

Confirmation experiments are carried out to validate experimental results. Confirmation experiment was carried out by replication and mean of this experiment was used to validate PCR-TOPSIS prediction value.

As shown in Table 10, power frequency response increased from 18 to 20 and partial discharge response greatly increased from 14.3703 to 20. This clearly shows that with PCR-TOPSIS method on production process can be increased through this research.

IV. CONCLUSION

Based on the results of the analysis that has been done, it can be concluded that:

1. Factors that influence the response quality on power frequency and partial discharge are oven temperature, oven time, mixing temperature, mixing time, clamping pressure, and clamping time.
2. The combination of control factors that reduce the total variance of power frequency and partial discharge simultaneously are oven temperature 110°C, oven time 240 minutes, mixing temperature 60°C, mixing time 100 minutes, clamping pressure 3 bar, and clamping time 20 minutes .
3. The results of the confirmation experiment on each response have higher optimization treatment conditions than the initial treatment conditions where the power frequency response increased 11.11% and the partial discharge response increased 39.17%,

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