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Total Harmonic Distortion and Power Factor Analysis of Thyristor Firing Angle on Electrostatic Precipitator in PLTU Unit 3 & 4 Pangkalan Susu Capacity 2 X 200 MW

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Abstract

The result from coal ash in the Steam Power Plant is called exhaust gas. Therefore, the impact of pollution makes the Electrostatic Precipitator is a piece of equipment that can handle these problems. The equipment has a voltage level regulation system that can create an electric field and capture charged ash. The thyristor system has a disturbance known as harmonics. A good treatment to handle that is to measure using a certain index, such as the Total Harmonic Distortion (THD), and its effect on the power factor. The following research is an alternative method to determine harmonic values using simulation modeling and theoretical calculations. This is because the company does not have a proper reference or procedure in determining the number of harmonic values. The company implements manual monitoring of observe panel in determining whether the setpoint is needed to increased or decreased. Therefore, this research was conducted to achieve these goals. The purpose of this research is to know the comparison of the results of the THD and power factor against the firing angle installed in the company and the firing angle variations of 30^0,60^0,90^0,$120^0$and 150^0. Then to know the resulting voltage and current waveforms from the effect of the firing angle on the ESP PLTU Pangkalan Susu through the MATLAB R2016a simulation. And finally to know the normal status of the ESP PLTU Pangkalan Susu based on the comparison with the IEEE reference standards. In this research, an analysis of the electrostatic precipitator system at PLTU Pangkalan Susu will be carried out by collecting the necessary data and the firing angle installed in the company. From the test results, it can be said that the THD value in the Electrostatic Precipitator system at PLTU Units 3 & 4 Pangkalan Susu is in the normal range. To find out the range of compatible firing angles on the system, it is also necessary to provide a test variable angle. Based on the test, it is known that the firing angle installed in the company is $46^0$with THDv and THDi of 4.01% and 3.61% respectively and the Power Factor is 0.84876. Whereas with the test variable angle, it is known that the good or normal THDv and THDi values are in the range 30^0 to 60^0 where the THDv value is in the range of 3.83% to 4.91%, and the THDi value is in the range of 3.50% to 4. 21%.

Keywords

Electrostatic Precipitator, Power Factor, Thyristor, Total Harmonic Distortion

INTRODUCTION

Air pollution in electrical energy generation, especially PLTU, is one of the problems that need to be considered by the public. The dangerous impact of the exhaust gas from burning coal that makes bad effects on health where the content is in the form of Carbon Monoxide, Sulfur Oxide, Nitrogen Oxide, Particulate, and other compounds [1]. For this reason, the PLTU has equipment that can handle these problems, namely the Electrostatic Precipitator (ESP). This device uses the principle of strong electric fields to create negatively charged electrodes to capture ash particles while positively charged ones are grounded so that the residual gas is discharged into the air while the ash is collected [2]. This system is supplied from a voltage controlled by the Thyristor for regulating the input voltage [3]. Then the output voltage will be stepped up by the transformer and then rectified by the rectifier for operation. The output voltage of the thyristor converter varies depending on the firing angle of the thyristor [4]. However, the use of a converter in the system will cause non-sinusoidal voltages or currents. The non-sinusoidal form of voltage or current will produce harmonics. High levels of harmonics in the system are undesirable because they can cause

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several losses [5]. Among them are increased distortion to input, malfunction of sensitive equipment, reduced efficiency, and more importantly the waste of electrical energy [6]. Thus, harmonic levels that are too high must be minimized. The low power factor that occurs in the AC regulator (thyristor) depends on the delay angle of the converter phase control. The phase control thyristor is turned on using a short pulse at the gate and is turned off by natural or line commutation, resulting in one pulse per half cycle of the converter input current. So that the level of harmonics and power factors greatly affect whether or not a device is normal, especially the Thyristor converter system [7].

RELATED CURRENT RESEARCH

Referring to the previous research, namely Faizal Arya Samman and friends with the title "Design, Simulation and Analysis of Harmonics on Single Phase Inverter Circuits" in 2015 stated that the conversion circuit using semiconductors resulted in large harmonic values. The large harmonic value affects the power factor of the system, causing a waste of energy [8]. This research is then continued by using an object in the form of an AC voltage regulation system on the Electrostatic Precipitator which consists of a back-to-back Thyristor circuit. Research that uses a back-to-back Thyristor circuit in regulating voltage has been conducted by Indah Pratiwi Surya [9]. This series is also very commonly applied to Electrostatic Precipitators in Steam Power Plants so that coal waste can be handled properly. In previous studies, researchers used simulation modeling methods in PSPICE OrCAD software so that modeling will be carried out using a different simulation, namely Matlab R2016a as a comparison. To conduct the research, the simulation modeling of this control system was carried out using Simulink Matlab.

In the simulation, the system will be assembled in the form of parameter blocks with the data that has been taken from PLTU Pangkalan Susu units 3 and 4 under the control of the company PT. Indonesia Power. By adjusting the firing angle in the simulation, namely 30^0,60^0,90^0,$120^0$and 150^0, the Vrms voltage, output waveform, THD, and power factor obtained through calculations will be known.

METHOD

A. Modeling Simulation

This research uses the MATLAB R2016a software system to compute and create modeling through the Simulink feature. The data from the Thyristor control system will be rearranged using a parameter block that was resembled by the system in the company. After compiling, the data then entered into the respective parameter blocks. A correct model is needed to get the expected research results. The system can be coupled to MATLAB software as shown below.

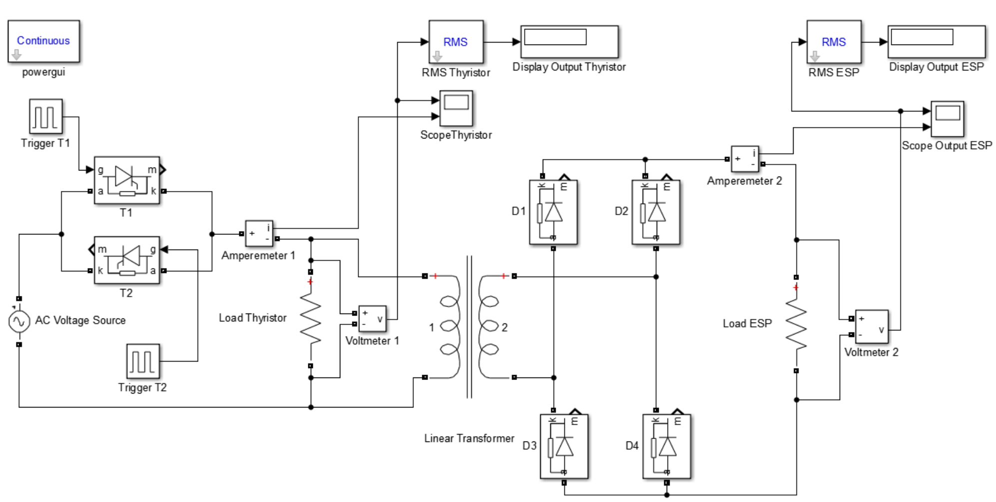

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Fig. 1. Series of ESP Thyristor System Simulation Modeling in Matlab

B. Collecting Data

This research requires direct observation in the field of data collection, namely the company PT. Indonesia Power which operates PLTU units 3 and 4 Pangkalan Susu. The researcher conducts a review of the principles of the research concept so that it is appropriate and similar to a known theory. The data include a single line diagram or system block of thyristor voltage control, system input voltage and current specifications, resistive loads, thyristor specifications, and several other supporting components. Besides, the most important data needed in this study is the firing angle that is applied to the company.

C. Processing Data

Researchers need to be run simulations that have been initiated and transient analysis to determine the Vrms voltage and the output waveform based on the firing angle effect. The value of the output voltage and the waveform can be seen how the effect of the firing angle on the thyristor control system. Researchers need to determine the THD value and the power factor which is influenced by the firing angle. To determine this, the simulation uses one of the types of analysis in MATLAB R2016a called Fast Fourier Transform (FFT) Analysis. This analysis will show the THD value for voltage and current based on the frequency order (n), while the power factor is obtained through the following calculation formula.

$$PFdist = \frac{1}{\sqrt{(1+THDv^2)}\sqrt{(1+THDi^2)}} cos\theta \tag{1}$$

D. Data Analysis

In this study, the research output is to determine the effect or relationship that occurs between the Vrms value, the output waveform, the THDv, and THDi values, and the power factor. In the data analysis of this research, a comparison is made between the simulation modeling results and the calculation results. The results of simulation testing can be found through the MATLAB R2016a software, while the calculation results can be found through the following calculation formula. The rms output voltage for load R can be determined as follows:

$$Vrms = \frac{Vm}{\sqrt{2}} \left[\frac{1}{\pi}(\pi - a + \frac{sin2a}{2})\right]^{1/2} \tag{2}$$

To get the THD value from the voltage used the equation:

$$THDv = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} \, x \, 100\% \tag{3}$$

Meanwhile, to get the THD value from the current, the equation can be used:

$$THDi = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \, x \, 100\% \tag{4}$$

Furthermore, to find out the system is in good condition or not, it is necessary to compare the THD harmonic values based on the reference standards set by the IEEE which can be seen in the table below.

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TABLE I
IEEE Reference Standards for determining the THDv limit based on the system voltage

Voltage System	Isc/Iload	THDi (%)
Vrms ≤ 69 kV	< 20*	5
	20-50	8
	50-100	12
	100-1000	15
	1000	20
69 KV <V rms ≤ 161 KV	< 20	2.5
	20-50	4
	50-100	6
	100-1000	7.5
	1000	10
Vrms > 161 KV	< 50	2,5
	≥ 50	4

* For all equipment the power generation is limited to <20 regardless of Isc / Iload value

TABLE III
IEEE Reference Standards for determining the THDi limit based on the system voltage

Voltage System	IHDv (%)	THDv (%)
Vrms ≤ 69 KV	3	5
69 KV < V rms ≤ 161 KV	1.5	2.5
Vrms > 161 KV	1	1.5

RESULT

The voltage level control system on the PLTU Unit Pangkalan Susu is composed of several components. The supply of voltages to operate ESP comes from the company's generation system which is 400 Volt. The Trigger Gate required by the Thyristor to be active is 0.8 - 2.5 volts. Also, the anti-parallel Thyristor circuit is protected with a Snubber circuit consisting of a 20 Ohm resistor and a capacitor of 1 micro Farad. The resistive load that is loaded on the system is 300 Ohm. Then the output voltage that has been processed on the Thyristor will then be increased in the Step-Up Transformer with a Primary rating of 400V / 50Hz / 206A and a Secondary 72KV / 50Hz / 0.8A. But in real operation, the average voltage is in the range of 35 kV to 60 kV only. The voltage is then rectified by the rectifier and ends in the Electrostatic Precipitator equipment which is loaded with a load of 68,000 Ohm to get a high voltage electric charge to catch dust.

In the company, the control system is implemented using a module, namely the Graphic Voltage Controller (GVC) Interface Board, which functions as a Power Optimizer. This module is placed on the control panel so that it is an integrated form compared to other modules. This module also uses an Arduino ATMega microcontroller. The last component is the Graphic User Interface (GUI), which is a display displaying legible parameters.

A. Voltage Vrms

Based on the circuit and data parameters that have been obtained from the company, the Vrms output voltage is found based on the MATLAB simulation test. Meanwhile, as a comparison, the output voltage Vrms is also displayed as a result of the calculation of the formula. The Vrms value which is influenced by the firing angle given to the Thyristor can be seen in the following graph.

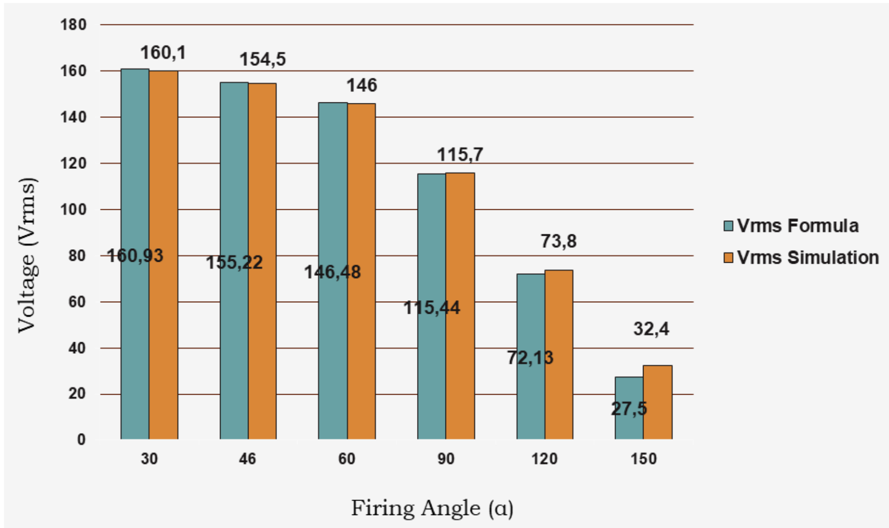

Fig. 2. Effect of Firing Angle on Voltage Vrms

From the results of the graph above, it is found that the Vrms value at the firing angle at the company is 46^0 at a value of 154.5 Volts. For the various firing angle given in the simulation, it is found that the Vrms value with the smallest firing angle of 30^0 is known to be 160.1 Volt and the largest firing angle of 150^0 is obtained at 32.4 Volt. Meanwhile, according to the calculation formula, it is found that the Vrms value with the smallest firing angle of 30^0 is known to be 160.93 volts and the largest firing angle of 150^0 is obtained at 27.5 volts. This shows that the greater the firing angle is given to the thyristor voltage level control system, the smaller the average output voltage value will be read. Based on the graph above, it shows that for angles of 30^0, 46^0, 60^0, $90^{0,}$ and 120^0, the average error person both values by calculation and simulation have a relatively small percent error (<10%). However, at 1500, the error person value based on the calculation is 17.82%. Based on the test results the output voltage is 32.4 volts and based on the calculation formula is 27.5 volts with a test ignition angle of 150^0. With the same angle, it is also known that the THDv value is 7.23% and the THDi value is 6.28%. Following the theories, it is stated that the greater the harmonic value contained in the system, it will cause a waste of electrical energy and decreased measurement sensitivity in the system. So that the harmonic value that has been obtained through the simulation at an angle of 150^0 shows that the value has a relatively larger difference. Besides, the angle 150^0causes a relatively large voltage regulation process, with an input voltage of 230.94 Volts to 32.4 Volts with a ratio close to 7: 1. This is also a factor in the large error value at angle 150^0.

B. Output Waveform

Based on the simulation design that has been carried out with the value of the firing angle on the thyristor as the independent variable, it can be seen that the output wave of the voltage and current are generated by the system. The waveform can be seen in the image below.

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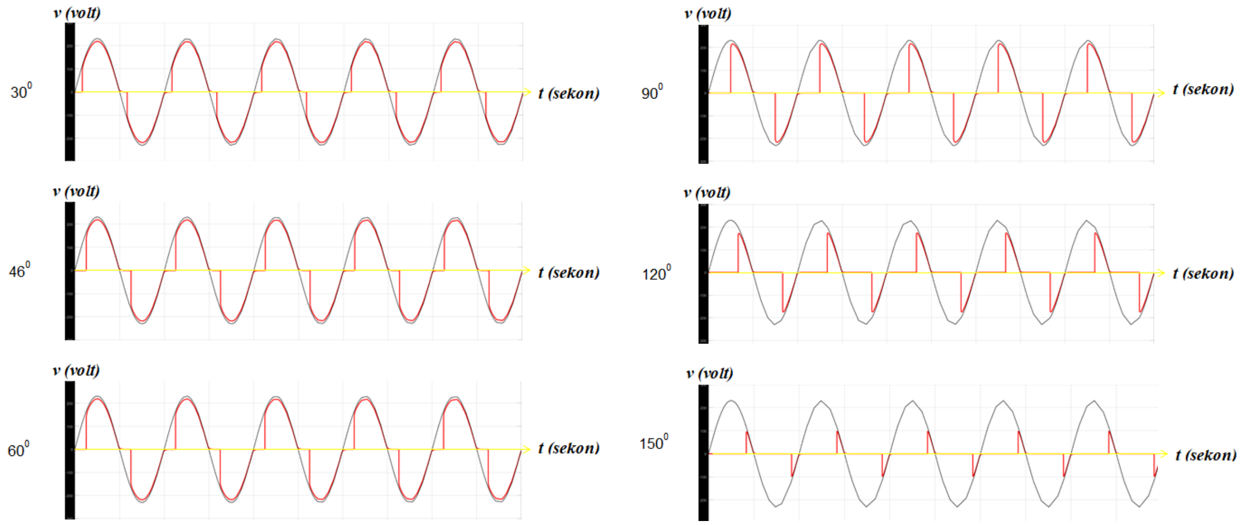

Fig. 3. Simulation Waveform Output Against Firing Angle

Based on the waves above, it is known that the greater the firing angle given to the Thyristor system, the greater intersection of the visible voltage waves. This is following the theory where the firing angle causes a delay in the time axis period t so that at a certain value the sinusoidal wave will activate. With this delay angle, the sinusoidal wave will appear smaller or show that the resulting voltage is smaller than the given input voltage.

C. Total Harmonic Distortion

After knowing the output voltage value of the Thyristor control system, the simulation can be continued with transient analysis to determine the harmonic value both in terms of voltage (THDv) and current (THDi) using Fast Fourier Transient (FFT) Analysis. By initiating the data and connecting the FFT Analysis with the simulation scope, for the 46^0 angles and also the firing angle for the Thyristor system with variations of 30^0,60^0,90^0,120^0 and 150^0 given, the THDv and THDi values are obtained as in the chart below.

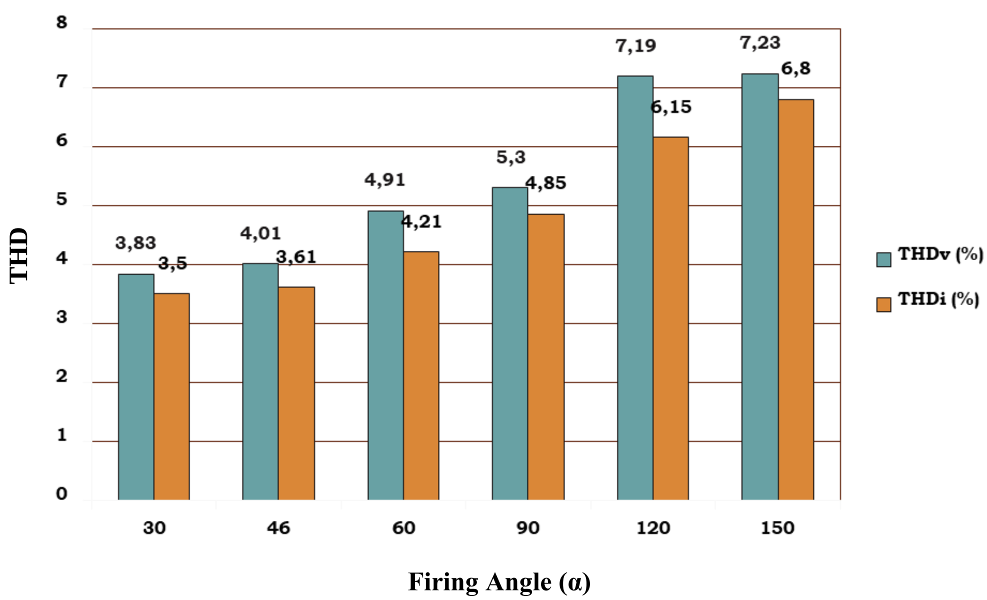

Fig. 4. Effect of Firing Angle on THDv and THDi Value

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In the simulation test results of the back-to-back Thyristor voltage level control system using MATLAB, it is known that the value of the firing angle given to the Thyristor affects the resulting Total Harmonic Distortion (THD) value. With the anti-parallel installed Thyristor, it explains that the voltage can be varied due to the sinusoidal time delay, which cuts off part of the existing input voltage. Based on the results of data processing, it is known that the greater the firing angle value, the non-linear load conversion system works harder. So that the resulting THD is even greater.

D. Power Factor

By knowing the results of the calculation of the Total Harmonic Distortion (THD) value, the distortion Power Factor can be determined using a formula. The distortion power factor value based on the firing angle can be seen in the graph below.

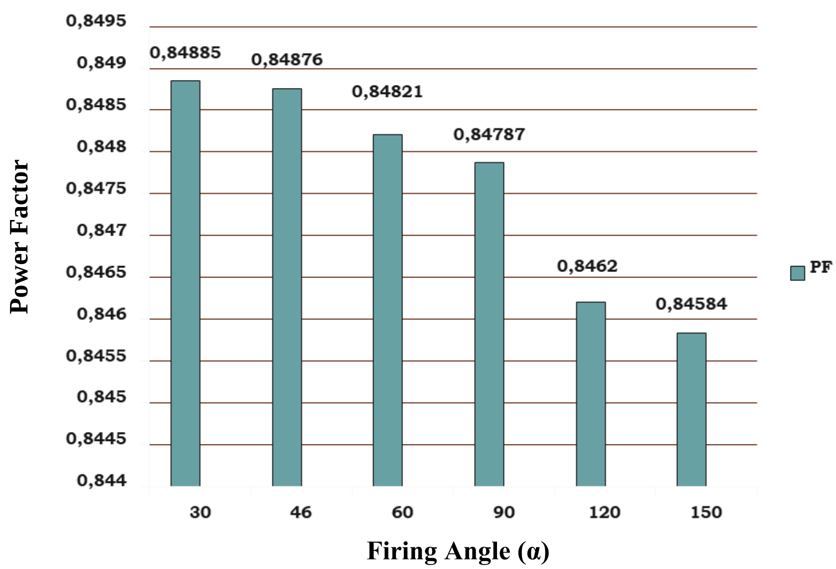

Fig. 5. Effect of Firing Angle on Distortion Power Factor

Based on the results of data processing, it is known that the greater the firing angle value, the lower the Distortion Power Factor value. The decline experienced seemed insignificant but was relatively very small. The value of the system power factor is 0.85 but after analyzing its effect on the THD value, it is known that the largest firing angle value of 150^0 only reduces the power factor to 0.84584.

E. Comparison of THDv and THDi Values Against IEEE Reference Standards

With the results of the THD test that has been carried out based on the simulation, a comparison can be given between the THDv and THDi values against the IEEE reference standards that have been set. With this comparison, it can be seen the condition of the voltage level regulation system from the harmonic side. The comparison can be seen in the following table.

Based on the simulation test table above, it is known that the value of the firing angle of the Thyristor system applied to the PLTU Unit Pangkalan Susu is 46^0. With this angle, the value of the Total Harmonic Distortion from the simulation is THDv of 4.01% from the limit 5% and THDi 3.61% from the limit 5%. Seeing the IEEE reference standard in providing limits on the THD value, the Thyristor Voltage Level Regulation system at PLTU Units 3 and 4 Pangkalan Susu is normal in its operation.

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TABLE IIII
COMPARISON OF THDV AND THDI VALUES AGAINST IEEE REFERENCE STANDARDS

Angle α	IEEE Standard	THD*v* Simulation	Result	THD*i* Simulation	Result
30^o	5%	3,83%	Normal	3,50%	Normal
46^o	5%	4,01%	Normal	3,61%	Normal
60^o	5%	4,91%	Normal	4,21%	Normal
90^o	5%	5,30%	Ineligible	4,85%	Normal
120^o	5%	7,19%	Ineligible	6,15%	Ineligible
150^o	5%	7,23%	Ineligible	6,80%	Ineligible

CONCLUSION

Based on the results of testing and analysis of the research, conclusions can be given that the greater firing angle given, produces the smaller Vrms output voltage value. Output waveforms can be seen in Figure 3.2 shows that the greater the firing angle is given, the greater intersection can be seen. So that the output wave that appears on the scope is getting smaller. The smaller output wave also indicates the smaller value of the resulting output voltage. The analysis then can show the greater firing angle given, produce the greater THD value. For the power factor, the greater firing angle given produces the smaller (decreasing) value of the resulting distortion power factor. From the simulation and analysis, the voltage regulating system of the Thyristor ESP PLTU Unit Pangkalan Susu can be found within the limits that eligible or normal.

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