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RESEARCH PAPER

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Development of TCR-FC Reactive Power Compensation Device with Fuzzy Logic Control in Electric Power Networks

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ABSTRACT

Utilization of electrical loads in predominantly inductive single-phase low-voltage power grids, the quality of electrical power becomes poor due to reactive power consumption resulting in a lack of power factor resulting in power loss, voltage drop, and decreased service life of the power grids. equipment. The research on reactive power compensation using TCR-FC aims to make improvements in improving the power factor in single-phase low-voltage electrical networks so that they have flexible control, do not experience excess compensation, have fast dynamic responses, and are space-saving. And can monitor voltage, current, and phase difference parameters through sensor readings to process data mathematically. When using electrical loads, the reactive power value is larger and the power factor is low below 0.85, the system controls the ignition angle of the TRIAC so that the current flowing into the reactor can be controlled by the reactive absorption measure of the fixed capacitor. So, it can improve the power factor. Simulation results can increase the power factor that exceeds the average value of 0.9 by 0.9797 with an error of 0.0288%. Hardware test results can increase the average power factor to exceed 0.9 by 0.9758 with an error of 0.1373%. in conclusion, reactive power compensation devices that use thyristor-controlled reactors and fixed capacitors can be more efficient than capacitor banks.

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1. INTRODUCTION

Good quality electrical resources for single-phase low-voltage electrical networks are very necessary. Good electrical power quality is a power factor or cos phi with a value range of 0.85 to 1 (Unity) and according to IEC 60364-8-1 if the power factor falls from 1.0 to 0.9 or below then the power used is less effectively 10% more current is required to supply the same load [1]. Because the electricity usage load for single-phase low-voltage PLN customers is generally inductive, it can cause a decrease in the power factor value which results in large reactive power consumption [3]. The power factor itself is a measure of the efficiency of the use of electrical power in a system that produces real work on electrical loads. Reactive power is still needed because the electric power is to build a magnetic field in inductive electrical loads, but this power does not directly produce real work. Some sources of electrical equipment that cause low power factors and voltage drops in single-phase low-voltage electrical networks are single-phase induction motors because induction motors work on light loads, the power factor is low and when fully loaded [4]. The economic disadvantage of a low power factor on the power grid is increased operational costs because systems with poor power quality tend to have low operational efficiency, resulting in damage to electrical equipment and increased repair or replacement costs [17]. The company is charged extra by the electricity provider for having poor power efficiency and thus has to supply more apparent power to support the active load requirements [11]. Operational losses are increased temperatures in electrical equipment and cables due to large currents, flicker disturbances can cause machines to stop or operate abnormally resulting in total damage to electrical equipment [2]. In general, reactive power compensation equipment consists of a capacitor bank that is installed in parallel with the load using a contactor switch [13]. Meanwhile, reactors are only often used in high voltage and extra high voltage power networks, such as the Extra High Voltage (EHV) Shunt Reactor [14]. Paying attention to these problems, we are motivated to

Conduct design research using a Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) to develop a reactive power compensator that can overcome reactive power reduction when using electrical loads in single-phase low-voltage power networks [15]. The TCR-FC circuit combines a reactor or inductor to absorb reactive power and a fixed capacitor to generate reactive power

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which is connected in parallel with a controlled turning angle on a sinusoidal wave using a Thyristor type TRIAC [10]. For the method of controlling the ignition angle on the Thyristor, use Fuzzy Logic Control [16]. With this research, it is hoped that it can improve power quality by reducing reactive power and increasing the power factor value beyond 0.9 when using electrical loads on single-phase low-voltage power networks [17].

The workings of the system for monitoring and improving the power factor are designed for single-phase low-voltage electrical networks with predominantly inductive electrical loads [18]. Then, in monitoring it will respond to the results of the readings and calculations of phase difference angles, active power, reactive power, and power factor, where if the power factor is below standard then the control can decide to provide an ignition angle to achieve the best power factor improvement set point for each variation in electrical load [19].

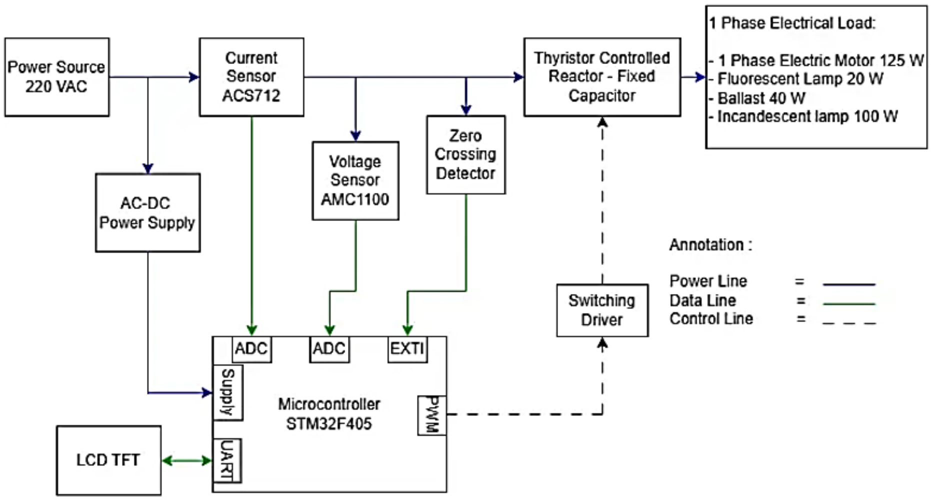

Fig. 1. Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) System Diagram

To design TCR-FC, a method is needed that will later be applied to the monitoring system and improve the power factor in single-phase low-voltage power networks when using electrical loads which can reduce the power factor [20]. The method that will be used is fuzzy logic control. Fuzzy logic control is applied when reading the power factor value which is not good so that it can help control in determining the TRIAC ignition angle which affects the work of the reactor or inductor [21]. The input parameters are the error value and delta error when reading a poor power factor, so data processing is carried out to obtain the best power factor value for each electrical load variation [22].

The purpose of this research is to improve power quality by reducing reactive power and increasing the power factor value to 0.9 when using electrical loads on a single-phase low-voltage electrical network. The contribution to this research is to design a Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) in developing a reactive power compensator that can overcome the reduction of reactive power in the use of electrical loads on a single-phase low-voltage electrical network. The TCR-FC circuit combines a reactor or inductor to absorb reactive power and a fixed capacitor to produce reactive power that is connected in parallel with a controlled firing angle on a sinusoidal wave using a TRIAC type Thyristor. For the firing angle control method on the Thyristor using Fuzzy Logic Control.

2. MATERIALS AND METHODS

In this reactive power compensation system, a circuit is needed that can be used as an AC-AC voltage controller in the form of a thyristor-controlled reactor and a fixed capacitor [23]. Thyristor-controlled reactors and fixed capacitors are used to regulate the voltage and current flowing into the reactor by adjusting the ignition angle of the TRIAC which will then be used to balance the absorption of reactive power from the load used [24]. Thyristor-controlled reactors and fixed capacitors are still chosen because they can increase or decrease reactive power absorption without causing surge currents in the reactive power compensation system so it is safer to improve the power factor [8]. The block diagram of this reactive power compensation system can be seen in Figure 1.

A. Power Quality

A single-phase power grid is a two-wire AC power grid commonly used in residential and small commercial applications [25-27]. These networks have lower efficiency, lower power output, and lower stability than other types of electrical power [28-30]. Electrical energy

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comes from potential differences, which produce charge currents. Electrical applications include power transmission lines and light bulbs. The rate of transfer of electrical energy in a circuit per unit of time is called electrical power. This is a measure of the amount of energy consumed in a period which is calculated using the Eq. (1) [16].

$$P = V \cdot I \cdot \cos \varphi \tag{1}$$

In terms of power quality, calculating the active power (P) value is important because with active power we can find out whether we can use electrical energy properly or not. Active power at AC voltage involves several parameters including (V) effective voltage in volts, (I) effective current in amperes, and cos phi (φ) or power factor which is the cosine of the phase angle between voltage and current. φ angle indicates the phase difference between voltage and current in the system, which depends on the nature of the load used. Power factor is a concept about the comparison between the real power unit Watt (W) and the apparent power unit Volt-Ampere (VA) in an AC electric power system. Real power is the result of instantaneous average work, while apparent power is the result of RMS current and voltage flowing into the network or circuit. Power factor is a measure of how effectively a circuit uses a given power. This can be expressed in decimal or percentage form. The tissue phase angle is Φ. Figure 2 shows a power triangle showing apparent power (W), high reactive power (VAR), and sloping side apparent power (VA).

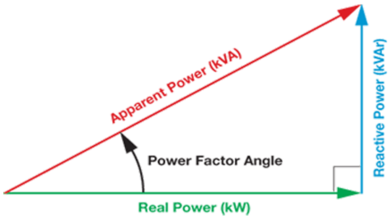

Fig. 2. Triangle of power

Phase shift is where two or more waveforms are not in line with each other. The amount of phase shift between two waves can be expressed in degrees. A waveform with a backward position is defined as a lagging waveform where the current is 90° behind the voltage based on Figure 3., while a waveform with a leading position is interpreted as a leading waveform where the current is 90° ahead of the voltage based on Figure 4.

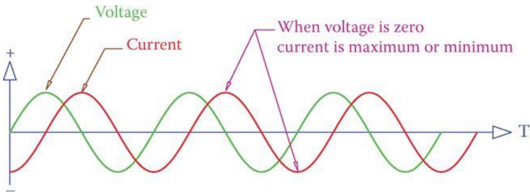

Fig. 3. Lagging Sinusoidal Waveform(Electrical Academia, n.d.)

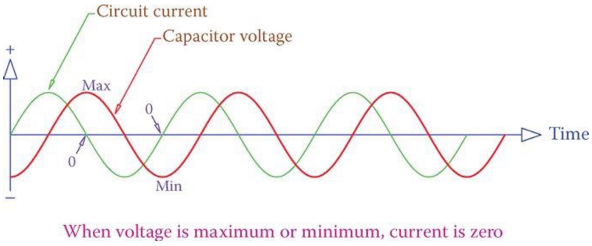

Fig. 4. Leading Sinusoidal Waveform(Electrical Academia, n.d.)

The power factor value depends on the phase difference between current and voltage. The AC power capacitor as a compensator connected to the network will cause the load current to lead by 90°, Ic = Im sin (ωt+90°). This causes the load current to be in phase with the voltage. Where the load current lagging behind by 90° will be compensated by the capacitor current leading by 90°, Ib = Ib sin (ωt+90°+90°) = Ib sin t. This is based on Figure 5. [5].

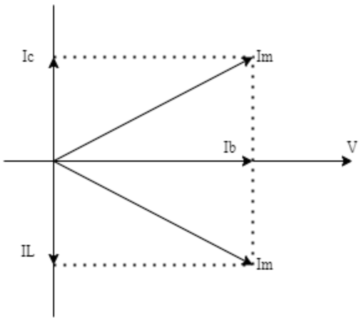

Fig. 5. Phasor Diagram Compensator Concept

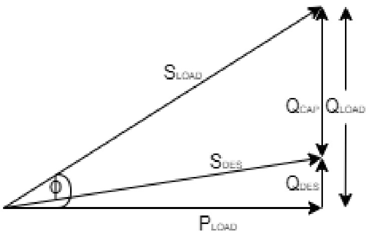

Fig. 6. Power Factor Improvement Concept

The concept of power factor improvement and the sum of real power, reactive power produces apparent power based on Figure 6.

$$S = \sqrt{P2+ Q2} \tag{2}$$

$$S = V \cdot I \tag{3}$$

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Power Factor :

$$\text{Power / Apparent Power} = PS = \cos\varphi \quad (4)$$

Apparent power, denoted by the letter (S), is the total amount of power supplied to an electrical circuit and is the combination of active power (power that produces real work) and reactive power (power stored and returned by inductive or capacitive components in the system). meanwhile, the power factor denoted as pf or cos phi (φ) is the ratio between active power (P) and apparent power (S) in an AC system. power factor measures how efficiently electrical energy is used in a circuit.

B. Thyristor Controlled Reactor dan Fixed Capacitor (TCR-FC)

Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) is an SVC from a combination of two opposing components, namely an inductor or reactor and a capacitor that can be controlled [18]. The TCR can only be regulated continuously in lagging reactive power conditions. To be set to leading, a fixed capacitor is connected in parallel with the TCR. The following is the Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) configuration based on. Two thyristors connected anti-parallel to an inductor or reactor in series on the TCR work like a bi-directional switch where the thyristor T1 conducts in the positive half wave and thyristor T2 conducts in the negative half wave [12].

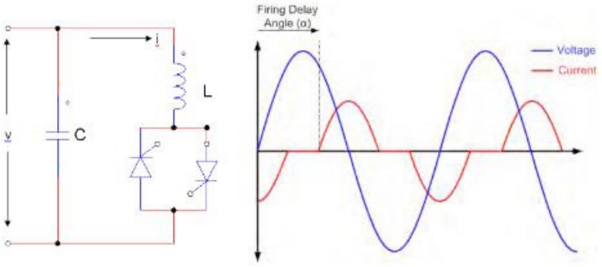

Fig. 7. TCR-FC Circuit and Output Waveform

The ignition angle (Firing Delay Angle) results in reduced power losses in the thyristor, but besides that it also results in harmonics which change the shape of the sinusoidal wave. The range for setting the ignition angle (α) is from 90° to 180°. When the angle is 90° it causes the thyristor to conduct fully, whereas when the angle is 180° the thyristor does not conduct or is in blocked mode. Turning angles between 0° and 90° are not permitted because they produce asymmetric currents in the DC components. DC components can cause increased harmonic distortion in the system resulting in voltage fluctuations, reduced system efficiency, and increased system reactive power demand. The effect of increasing the ignition angle is to reduce the basic harmonic component of the current, while the inductance value in the reactor or inductor will increase and the reactive power will decrease in direct proportion to the current. The following is a calculation of the components contained in the thyristor-controlled reactor and fixed capacitor circuit.

$$Q_C = P \times \tan(\cos{-1}\theta 1 - \cos{-1}\theta 2) \quad (5)$$

$$X_C = V2Qc \quad (6)$$

$$C = 12 \cdot \pi \cdot f \cdot XC \quad (7)$$

$$X_L = VI \quad (8)$$

$$L = XL2 \cdot \pi \cdot F \quad (9)$$

In designing the thyristor-controlled reactor and fixed capacitor circuit, there are two main components to compensate for reactive power, namely the capacitor (C) and the reactor or inductor (L). In calculating the capacitor value, you must obtain the reactive capacitive (QC) value by knowing the power factor before repair and the desired power factor target after repair so that you can know the reactive power requirements to compensate for it. because Eq. (7) requires a capacitive reactance value (XC), the voltage is divided by the capacitive reactance. because equation (7) requires a capacitive reactance value (XC), the voltage (V2) is divided by the capacitive reactance. In calculating the inductor value (L) you must know the inductive reactance value (XL) because the results of this calculation correlate with the inductor value. Figure 8. is a system flowchart for the entire equipment which illustrates the system's path from the voltage source to the electrical load through the main system, namely voltage sensors, current, zero crossing detector, etc. The way it works is when it detects voltage and current, it is read on the microcontroller and then sent to the TFT LCD, then the zero crossing detector reads each zero point on the AC voltage to calculate the phase difference based on time according to the formula process, then each cos and sin is used for power calculations active, power factor, reactive power then it can display the condition before repair on the TFT LCD. If the power factor condition is less than 0.9 or the voltage is less than 220 VAC, it means lagging, then a fuzzy process is carried out, whereas if the power factor condition is less than 0.9 or the voltage is more than 230 VAC, it means leading, then a fuzzy process is carried out. If it has been evaluated, then read the power factor again whether it has passed these two conditions or not and if

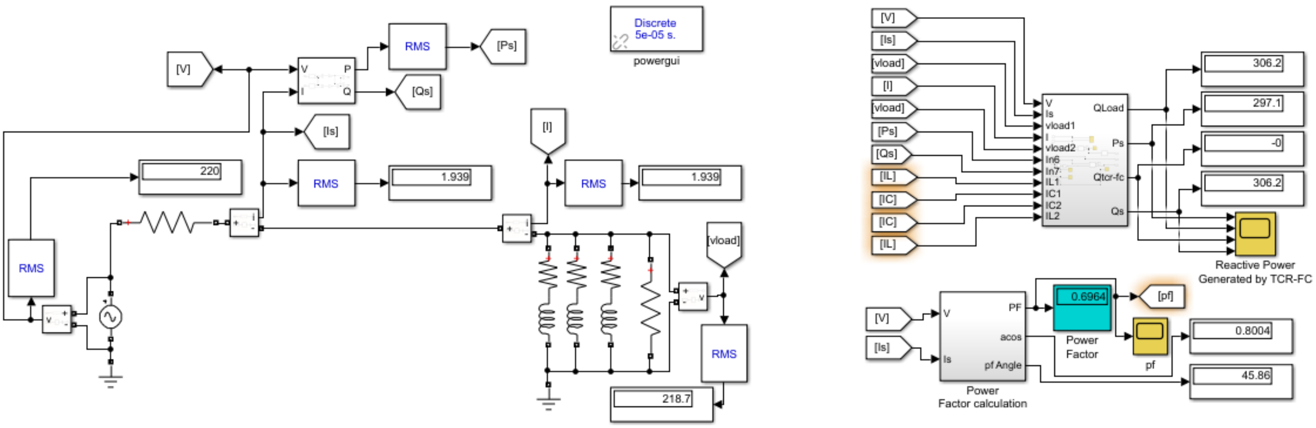

Fig. 9. Simulation Without TCR-FC Using 4 Electrical Loads

the switch is OFF with the symbol 0 or LOW then the TCR-FC system is turned off so the system stops operating.

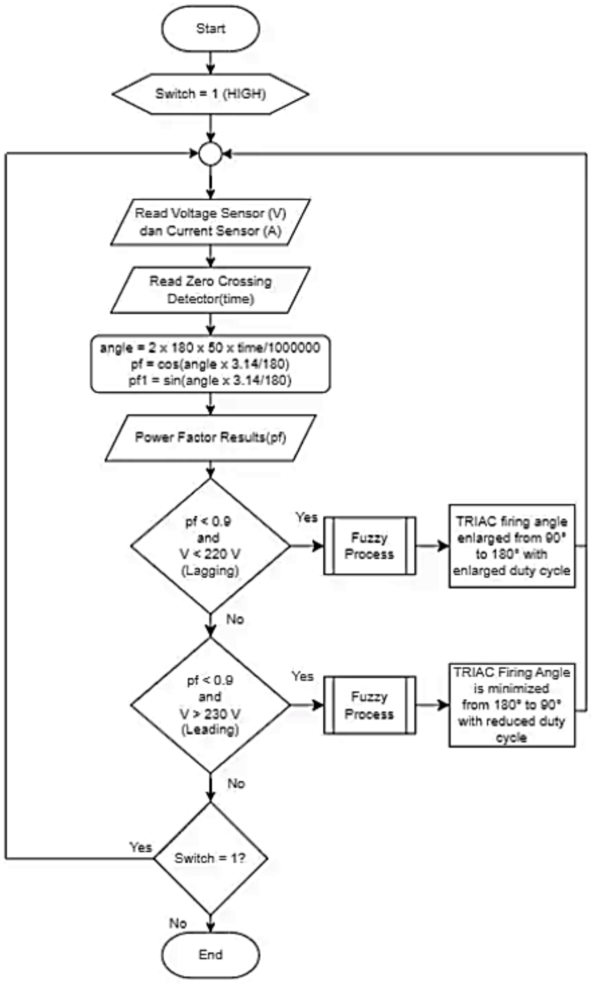

Fig. 8. TCR-FC System Flow Diagram

2. RESULTS

In this research, to obtain results, simulation and hardware testing were carried out to find out the various characteristics of each variation of electrical load used. Simulation testing carried out via MATLAB software will be carried out twice, in which the test will be done using an open loop simulation by testing how much power factor improvement is based on changes in each TRIAC ignition angle from 90° - 180°, while the next test will be carried out using a closed loop simulation using test how well controlling the TRIAC ignition angle improves the power factor until it reaches the best value.

A. Closed Loop System Integration Simulation

The Thyristor Controlled Reactor and Fixed Capacitor (TCR-FC) simulation using fuzzy logic control aims to show that the designs made in the simulation can be used in real conditions to compensate for the reactive power of single-phase low-voltage electrical networks. Previously, a simulation was carried out without using fuzzy logic control to find out the value before compensating the reactive power which was compared with after using fuzzy logic control whether it could improve the power factor or not. For the simulation circuit without TCR-FC, it can be seen in Figure 9. It is hoped that the Thyristor Controlled reactor and Fixed Capacitor simulation can detect variations in the electrical load used, and then control the PWM signal to set the right ignition angle to achieve the best power factor improvement at each electrical load variation. It can be seen from Figure 10 that the power factor measurement results for a 125W single-phase electric motor load, 36W ballast, 20W TL lamp, and 100W incandescent lamp without thyristor controlled reactor and fixed capacitor are 0.6964. Because there is no control to regulate the size of the reactive power compensation, which means that the reactive power of the load has a large, constant value, the reactive power produced by the single-phase low-voltage electrical network source supplies the electrical load so that the power factor becomes low and the efficiency of the active power is

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reduced. The following is a table listing the tests with variations in the electrical load used

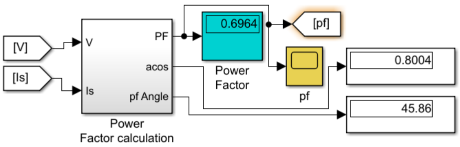

Fig. 10. Power Factor Measurement Results Without TCR-FC Using 4 Electrical Loads

Table 1. Simulation Results on Variations in Electrical Load Used Before Connecting the TCR-FC

No.	Electrical Load	Current (A)	Active Power (W)	Reactive Power (VAR)	Power Factor	Power Factor Angle (°)
1	1-Phase Electric Motor 125W, TL Lamp 20W, 100W Lamp, Ballast 36W	1.939	297.1	306.2	0.6964	45.86
2	1-Phase Electric Motor 125W, Ballast 36W, 100W Lamp	1.663	268.8	248.2	0.7347	42.72
3	1-Phase Electric Motor 125W, TL Lamp 20W, 100W Lamp	1.53	277.2	190.8	0.8237	34.54
4	1-Phase Electric Motor 125W, Ballast 36W	1.371	169.7	249.2	0.5628	55.75
5	1-Phase Electric Motor 125W, TL Lamp 20W	1.189	178.1	191.6	0.6809	47.09
6	TL Lamp 20W, 100W Lamp, Ballast 36W	1.039	147.2	174.9	0.6438	49.92

In making fuzzy logic control there are 2 inputs that are converted into two fuzzy variables, namely Error (E) and delta Error (dE)(Institute of Electrical and Electronics Engineers, n.d.). These two variables will later be processed through Fuzzyfication, Fuzzy Inference System, and Defuzzification which will produce an output in the form of a duty cycle quantity for generating PWM as a control signal for the thyristor or SCR in Figure 11. which is installed in parallel but the anode and cathode on the thyristor are the same as the other. others are in opposite directions so that positive cycle and negative cycle AC electric current can pass through the thyristor. The PWM control signal for the thyristor or SCR functions to control the ignition angle of the AC voltage which produces a delayed ignition voltage for a predetermined angle so that voltage switching occurs where the reactor or inductor cannot supply completely so the current flowing to the inductor is also incomplete and interrupted. -separated.

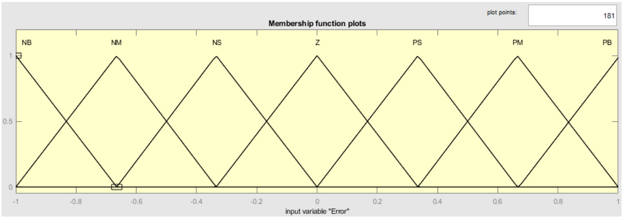

Fig. 11. Closed Loop TCR-FC Simulation With Fuzzy Logic Control

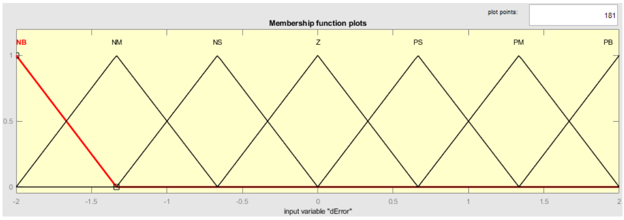

Fig. 12. Input Error Membership Function

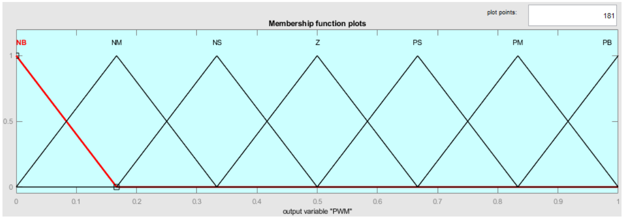

Fig. 13. Input dError Membership Function

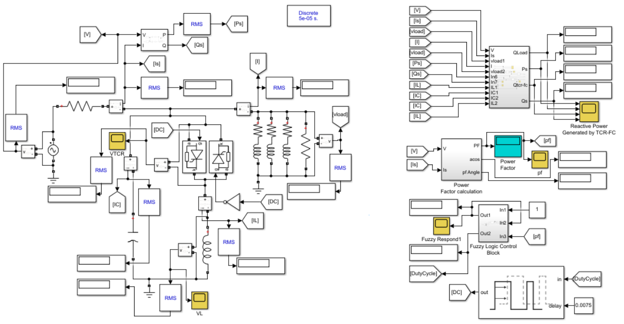

Fig. 14. Output Duty Cycle Membership Function

In Figure 12. shows the membership function of the Error variable with a range of -1 to 1, while in Figure 13. shows the membership function of the dError or delta Error variable with a range of -2 to 2. Then, in Figure 14. is the output membership function in the form of a duty cycle with range 0 to 1. The results of the fuzzification process are processed at the fuzzy inference system stage by arranging and considering the predetermined rule base. The following is an example of Table 2. fuzzy rule based.

Table 2. Fuzzy Rule Based.

E/dE	NS	Z	PS	PM	NM	NB	PB
NB	NB	NB	NS	NS	NB	NB	Z
NM	NM	NM	NS	Z	NB	NB	PS
NS	NM	NS	Z	PS	NM	NB	PM
Z	NS	Z	PS	PM	NM	NM	PM
PS	Z	PM	PM	PM	NS	NM	PB
PM	PS	PM	PM	PB	Z	NS	PB
PB	PM	PB	PM	PB	PS	Z	PB

It can be seen that to determine the control work that can determine the amount of output in the form of the duty cycle. The output from the fuzzy inference system will be processed as defuzzification input which is expressed in the form of a fuzzy set of real numbers. Defuzzification is the process of converting fuzzy output values back into crisp output data or classic output to the control object. The defuzzification method used is the Centroid Method.

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Where the crisp solution output is obtained by taking the center point. The output is in the form of a duty cycle value of 0 – 1 to keep the output voltage constant.

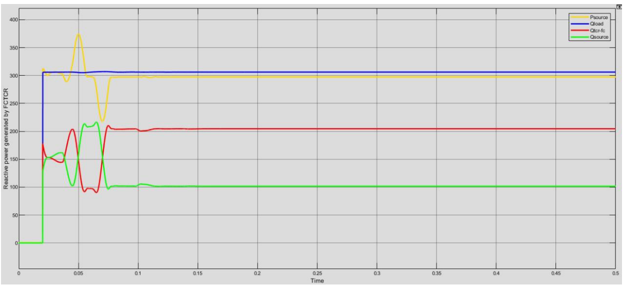

Fig. 15. Results from TCR-FC with Fuzzy Logic Control as Reactive Power Compensation

Figure 15 shows one of the results of a closed loop integration simulation with 4 electrical loads according to no. electrical load 1 as stated in table 3. 1 that there is reactive power compensation where the reactive power produced by the TCR-FC compensates or replaces the reactive power losses from the green source ($QSource$), but the value of the reactive power produced by the TCR-FC is red ($QTCR{-}FC$) is smaller than the load reactive power wave which is blue ($QLoad$) and the active power of the source ($PSource$). This compensation can reduce the use of reactive resources so that it falls into a good power factor range by obtaining a power factor value of 0.9464 and a source reactive power value of 49.42 VAR, so the electrical load is inductive, the results of the fuzzy power factor wave can be seen Figure 16.

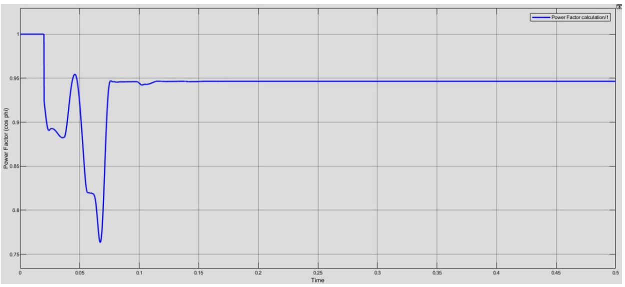

Fig. 16. Results of Power Factor Waves with Fuzzy

From Figure 16. shown above, the results of the power factor waves in the thyristor-controlled reactor and fixed capacitor which have used the fuzzy logic control method can overcome improvements in power factor where the waves control the ignition angle to influence the best power factor value. and has reached a steady state in less than 0.15s. The following is a table of experiments with various types of electrical loads that can reduce the power factor value.

Table 3. TCR-FC Closed Loop Integration Simulation Results

No. Electrical Load	Current (A)	Active Power (W)	Source Reactive Power (VAR)	Load Reactive Power (VAR)	TCR-FC Reactive Power (VAR)	PF Simulation	PF Theory	%Error PF
1	1.939	297.1	306.2	306.2	204.6	0.6964	45.86	0.0070
2	1.663	268.8	248.2	248.2	195.7	0.7347	42.72	0.1549
3	1.53	277.2	190.8	190.8	160.5	0.8237	34.54	0.0011
4	1.371	169.7	249.2	249.2	203.7	0.5628	55.75	0.0040
5	1.189	178.1	191.6	191.6	171	0.6809	47.09	0.0040
6	1.039	147.2	174.9	174.9	159.2	0.6438	49.92	0.0016
Rata – Rata Nilai						0.9797	0.9795	0.0288

B. TCR-FC Hardware Testing with Fuzzy Logic Control

In the TCR-FC test to control the switching of the TRIAC IC TCA 785 driver using a PWM signal from the microcontroller, as in Figure 17. Before entering pin 11 on the TCA 785 IC to control the TRIAC, a circuit is needed that can generate voltage from the STM32F4 microcontroller and filtering so that The voltage required for pin 11 is a constant DC voltage in the form of a straight signal with the FOD3182 circuit accompanied by a filter. For PWM signals from fuzzy logic control processing on the microcontroller. In the fuzzy logic control that has been created, the input used is error and delta error which takes the value of the power factor, then the resulting output is a pwm signal with a limit of 50 - 100% duty cycle. This refers to the ignition angle control on the TRIAC which can be converted to match the ignition angle to the given duty cycle value.

Fig. 17. TCR-FC Hardware Testing With Fuzzy Logic Control

Table 4. Test Results on Variations in Electrical Loads Used Before Using TCR-FC With Fuzzy Logic Control

No. Electrical Load	Voltage (V)	Current (A)	Active Power (W)	Source Reactive Power (VAR)	Power Factor (cos φ)
1.	225.4	1.991	307	322	0.688
2.	225.3	1.704	280	260	0.733
3.	227.5	1.545	294	190	0.833
4.	225.8	1.165	191	181	0.702
5.	226	1.406	186	255	0.589
6.	226	1.073	150	189	0.523

Table 5. TCR-FC Test Results with Fuzzy Logic Control on Electrical Load Variations

No. Electrical Load	Voltage (V)	Current (A)	Active Power (W)	Source Reactive Power (VAR)	TCR-FC Reactive Power (VAR)	PF Theory (cos φ)	PF Practical (cos φ)	%Error PF
1.	224.3	1.433	310	84.4	205	0.965	0.964	0.104
2.	228	1.280	289	38.2	210	0.993	0.991	0.206
3.	224.3	1.271	283	34.8	185	0.993	0.992	0.101
4.	224.3	0.956	192	44.9	204	0.975	0.974	0.103
5.	223.7	0.817	182	48.2	205	0.968	0.966	0.207
6.	227.3	0.709	156	40	188	0.969	0.968	0.103
Rata – Rata Nilai						0.9772	0.9758	0.1373

Can be seen in Table 1. No. load is a list of variations in the electrical load used which is above Table 4. to make

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it easier to include the electrical load in this table the test value is known before improving the power factor using TCR-FC in a closed loop with fuzzy logic control.

3. DISCUSSION

A. Closed Loop System Integration Simulation

It can be seen in Table 1. This is a simulation without TCR-FC and fuzzy logic control which contains a list of variations in the electrical load used so that you can determine the effect of using the electrical load causing a reduction in the power factor value. Then, it can be seen in Table 3. It is a TCR-FC simulation with fuzzy logic control which in No. The electrical load refers to Table 1. in number order and the use of electrical load variations to simplify the data collection in Table 3. From these two tables, it can be compared that TCR-FC can improve the power factor exceeding 0.9 or close to 1 (unity). Apart from that, it can be seen that reactive power compensation occurs where when the load reactive power is reduced by the TCR-FC reactive power, the source reactive power becomes smaller so that reactive power consumption is reduced, the power factor value becomes better because basically the smaller the source reactive power value, the better and maintained the reactive power consumption.

B. TCR-FC Hardware Testing with Fuzzy Logic Control

In electrical load variations No. 1 in compensating for reactive power, controlling the firing angle or ignition angle of 176.4°, which achieves an improvement in power factor reaching 0.964 with reactive power from the supplying electricity network of 84.4 VAR, while the reactive power produced by TCR-FC is 205 VAR. It can be seen that the electric current in the network before improving the power factor using TCR-FC in a closed loop was 1.991 A and after improving the power factor using TCR-FC in a closed loop it became 1.433 A, which resulted in a reduction in electric current so that losses could be overcome. copper in conductor lines and power losses. The difference in value between theoretical PF and practical PF is relatively small at 0.104%.

In electrical load variations, No. 3 in compensating for reactive power controls the firing angle or ignition angle of 126° which achieves an improvement in power factor reaching 0.992 with reactive power from the power supply network source of 34.8 VAR, while the reactive power produced by the TCR-FC is 185 VAR. The improvement in power factor by compensating for reactive power can be seen from the change in the reactive power value of the source before and after, where the reactive power value becomes approximately small. The smaller the reactive power value, the better the power factor in the system.

Of the six load variations, controlling the TRIAC ignition angle using fuzzy logic control has been carried out quite well because of the limitations in the control so that the PWM signal provided can change according to the conditions of the installed electrical load. The better the power factor value, the smaller the current and reactive power of the source because electrical power efficiency occurs with more ideal flowing current, so it can overcome copper losses in the conductor path and power losses. This means that the efficiency of power use in the system increases, as less reactive power is supplied from the source, reducing power losses and improving system performance. Changes in the voltage value of the electrical network system can change over time but are still in the range of 220 ~ 230 VAC. From all tests with variations in electrical load, the average power factor was 0.9758, and comparing the theoretical power factor value with the practical power factor value taken from the LCD readings resulted in an error value that had an average error of 0.1373%.

The fuzzy logic control method, when integrated with Thyristor Controlled Reactor and Fixed Capacitor equipment, has some weaknesses, it is not suitable for fast dynamic change conditions due to its slow processing of rules, the fuzzy system is not capable enough in the event of a large disturbance that is not contained in the fuzzy rules so that the performance of the TCR-FC is not optimal, and there is no standard method for determining the most suitable fuzzy rules for all operating conditions because if the operating conditions of the system change, the fuzzy parameters may no longer be appropriate, so additional adaptive algorithms are needed. In TCR-FC with fuzzy logic control is helpful in improving power system stability, where its adaptive response to dynamic load changes helps maintain voltage quality. In addition, fuzzy logic is able to optimize reactive power compensation, reduce power losses, and improve distribution efficiency. However, issues that arose when it was implemented was the difficulty of adjusting the parameters, which requires advanced hardware knowledge to develop successful fuzzy rules. Fuzzy systems may not be ideal for handling extreme changes in certain situations. However, its long-term benefits make it a promising solution for modern power systems.

4. CONCLUSION

The purpose of reactive power compensation research using TCR-FC is to make an update in improving the power factor in a single-phase low-voltage power grid so that it has flexible control, does not experience

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overcompensation has fast dynamic response, and space saving. Based on data obtained from planning and integration testing as well as obtaining an analysis of the method used, when controlling the TCR-FC for reactive power compensation manually it lacks precision, it is different from when done in an open loop and closed loop because the PWM signal is issued directly from the microcontroller so it's more precise. When the PWM signal is controlled by fuzzy changes or can be controlled when the detected electrical load is different, it produces different ignition angles so that it can still produce a good power factor exceeding the value of 0.9 with an average error of 0.1373% and The average practice power factor value is 0.9758. Apart from that, the TCR-FC simulation with fuzzy logic control was able to produce a good power factor exceeding 0.9 with an average error of 0.0288% and an average simulation power factor value of 0.9797. to develop reactive power compensation devices using thyristor controlled reactors and fixed capacitors, more sophisticated control systems or methods are needed to improve control performance in improving power factor.

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