Modification Design of Solar Tracker and MPPT on Photovoltaic Systems using PSO based Fuzzy Type-2 Controller

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Abstract : Photovoltaic (PV) systems are a promising renewable energy source, but their efficiency is affected by the angle of incidence of sunlight. It is necessary to have a control system for both light capture and optimizing PV power output. When capturing sunlight by PV, a conditioner is needed in the form of a solar tracker so that the light radiation received can be maximized. Meanwhile, the output power from PV can also be optimized using the MPPT (Maximum Power-Point Tracking) method. Both optimizations use Fuzzy Type-2 which optimizes the membership function value using the PSO (Partical Swarm Optimization) algorithm. In the Photovoltaic system, the power produced by the solar tracker system can increase by 3.25% and the energy increases by 14.76% when compared to the PV-fixed system. The output power of the solar tracker can be further increased using MPPT PSO based Fuzzy type-2, so that the system output power can increase to 759 watts and the energy increases up to 4.3 times.

Keywords : MPPT; Tracker; Photovoltaic; Fuzzy type-2; PSO

1. INTRODUCTION

Photovoltaic (PV) systems are a promising renewable energy source, but their efficiency is affected by the angle of incidence of sunlight. Solar tracking systems can improve the efficiency of PV systems by orienting the panels towards the sun.

Control methods to stabilize PV output power also vary. Optimizing PV output power generally uses two methods, namely maximizing solar radiation reception and also maximizing PV power output. The solar tracker method aims to maximize the capture of sunlight sources by following the angle of the sun's movement. Research on solar trackers has been carried out by [1] by adjusting the pitch angle and yaw angle to follow the movement of the sun. Control both corners using Fuzzy-PSO logic [2]. The research results show that with the solar tracking mechanism, the system output power

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research results show that with the solar tracking mechanism, the system output power efficiency increases by up to 60%. The output power of the PV can then be maximized again through the MPPT (Maximum Power-Point Tracking) mechanism. Other research regarding stabilizing output power through the MPPT mechanism in PV has been carried out by [3], [4]. The control given to this PV system is more or less the same as the control given to a wind turbine system, which produces a PWM signal as input from the buck-boost converter. The output power resulting from this research shows a stable response [5].

In PV systems, it will be more optimal if solar tracker logic and MPPT control are implemented. So, in this research, we will focus on designing MPPT control systems PVs as well as designing solar trackers for PVs. Selection of control mechanisms to maximize and stabilize power at both sources must also be considered. Based on previous research, the MPPT algorithm and solar tracker controller that can be used next are Fuzzy logic whose membership function values are tuned using the PSO (Particle Swarm Optimization) algorithm.

2. METHODOLOGY

A solar tracker is needed so that PV panels can follow the direction of the earth's rotation towards the sun so that the power produced by PV is more optimal [6], [7]. So, the solar tracker system requires a mechanism to read the position (altitude angle and azimuth) of the sun, a dc motor drive system to direct the PV according to the position of the sun. Meanwhile, in the MPPT mechanism, the output electrical power from the PV goes to the buck-boost converter circuit to find the maximum power point.

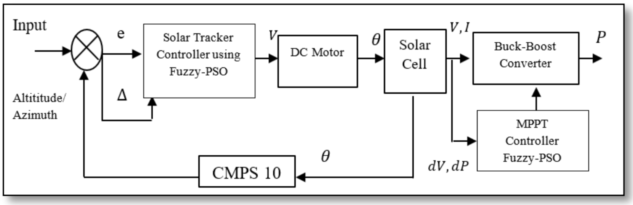
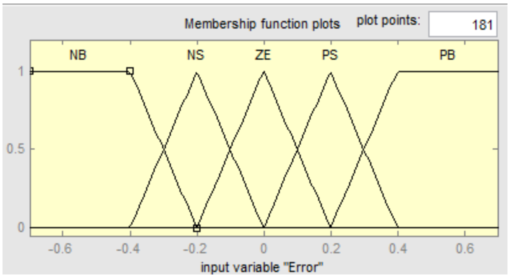


Fig. 1. Block diagram of solar tracker and MPPT on PV.

2.1. Solar Tracker on Photovoltaic uses a Fuzzy Controller

Solar tracker modeling is carried out using a fuzzy controller [8], [9]. The type of solar tracker used is passive, so the angles used are altitude and azimuth angles. So, the solar tracker is only on two axes for PV [10]. The input value in this solar tracker mechanism is the position of the sun (altitude angle and azimuth) while the output is the motor angle deviation. To drive the motor, it is necessary to control the input voltage on the dc motor so that the motor output angle matches the set point [11]. There are two motors (pitch and yaw) each of which uses a fuzzy controller [12].

The membership function designs of the fuzzy for pitch and yaw angle motors are shown in Figures 2 and 3 respectively. Meanwhile, the membership function values of the two fuzzy are shown in Tables 1.



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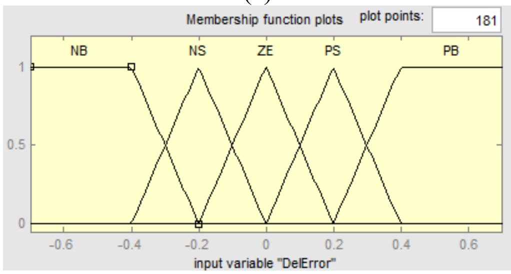

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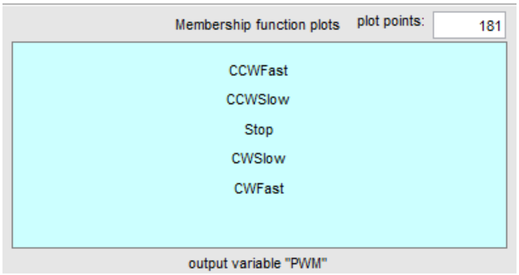

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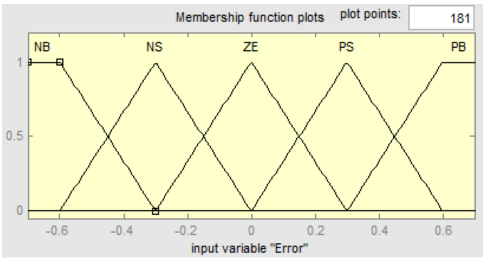
Fig. 2. Membership Function Variable input (a) error and (b) delta error and (c) output on solar tracker pitch angle control



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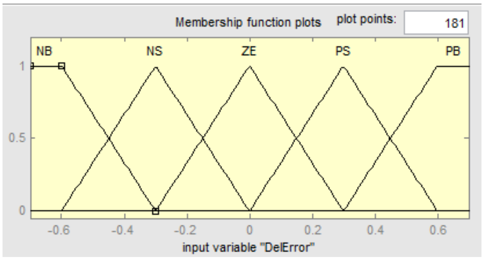

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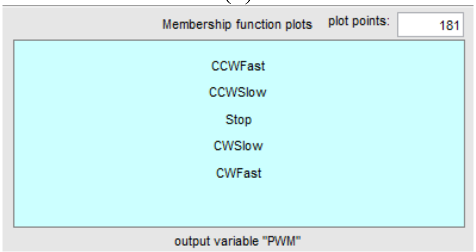

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Fig. 3. Membership Function Variable input (a) error and (b) delta error and (c) output on solar tracker yaw angle control

Determining the fuzzy membership function for this system is done by trial and error by dividing the motor PWM value into 5 parts [13]. The motor PWM value ranges from -255 to 255. Where, a negative value indicates the motor rotates counter-clockwise and vice versa, a positive value indicates the motor rotates clockwise. Meanwhile, the speed is directly proportional to the PWM value. The closer to 0, the slower the motor speed. The following is the distribution of membership function values as shown in Table 1.

TABLE I. VALUE OF MEMBERSHIP FUNCTION FUZZY INPUT AND OUTPUT VARIABLES ON SOLAR TRACKER

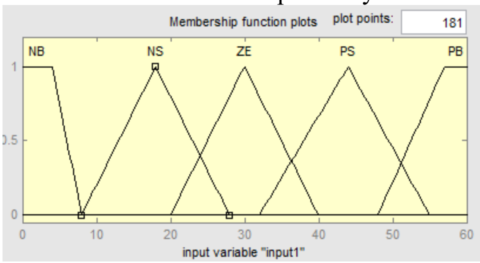
	Error / Delta Error of Pitch Angle	**Error / Delta Error of Yaw Angle**	**Output Pitch / Yaw Angle**
NB	[-3 -0.7 -0.4 -0.2]	[-3 -0.7 -0.6 -0.3]	CCWFast [-255]
NS	[-0.4 -0.2 0]	[-0.6 -0.3 0]	CCWSlow [-170]
Z	[-0.2 0 0.2]	[-0.3 0 0.3]	Stop [0]
PS	[0 0.2 0.4]	[0 0.3 0.6]	CWSlow [170]
PB	[0.2 0.4 0.7 3]	[0.3 0.6 0.7 3]	CWFast [255]

Determining the parameter rules for fuzzy is also done manually with a design from the researcher. There are two inputs to fuzzy, namely the error value and delta error between the sun's position and the PV tilt position. Meanwhile, the output value is a PWM value to regulate the DC motor voltage which is then used to rotate the PV being used so that the PV tilt angle will match the position of the sun at that time. The response from the fuzzy design is used as a reference when designing. The set points used are the azimuth and altitude values of the sun's position.

2.2. MPPT on Photovoltaics uses a PSO based Fuzzy Controller

The MPPT control mechanism on the Solar Tracker is the uses the value of changes in power and changes in output voltage from the current and previous PV [14], [15]. This value is then called error as the first input to the fuzzy controller. Meanwhile, the second input is the value of the difference between the current error and the previous error. The output from Fuzzy is a duty cycle value which will then be converted into a PWM value for input to the buck-boost converter on the PV.

Determination of membership function parameters in fuzzy was initially carried out manually using a design from the researcher. The Fuzzy Membership Function value on the MPPT Solar Tracker is shown in Figure 4, while the fuzzy parameters and their rules are shown in Tables 3 and 4 respectively.



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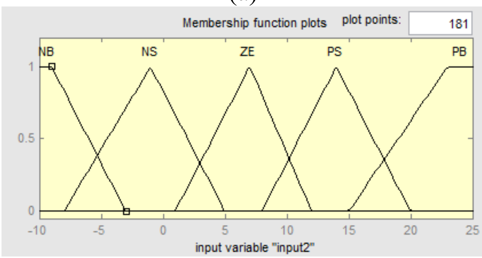

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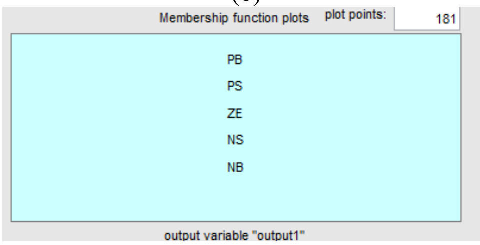

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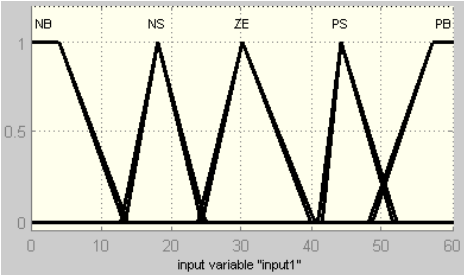
Fig. 4. Membership Function Variable input (a) error and (b) delta error and (c) output on the MPPT solar tracker control

PSO modeling was carried out using scripts in MATLAB. The boundaries of the fuzzy controller are optimized using the Particle Swarm Optimization (PSO) algorithm. After optimization, new fuzzy boundaries will be obtained based on the smallest MSE (Mean Square Error) value. The Fuzzy-PSO Membership Function tuning value on the MPPT Solar Tracker is shown in Table 5.



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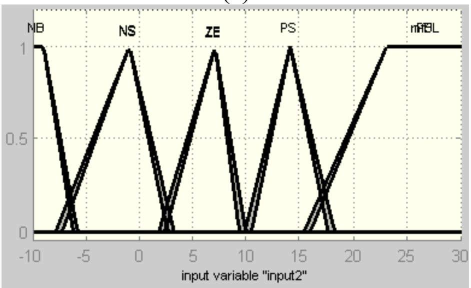

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Fig. 5. Membership Function Variable input (a) error and (b) delta error Fuzzy Type 2 on MPPT solar tracker control

The next step is to make the fuzzy that has been optimized using the PSO algorithm into Fuzzy type 2 by changing the membership function value from fuzzy-PSO which has 2 boundaries (right and left) to 4 boundaries, namely (top right, bottom right, bottom left and top left). Determination of the limit is based on the FOU (Footprint of Uncertainity) value used in the fuzzy. In this study, the FOU value used was 0.3. Membership function with FOU 0.3 is shown in Figure 5.

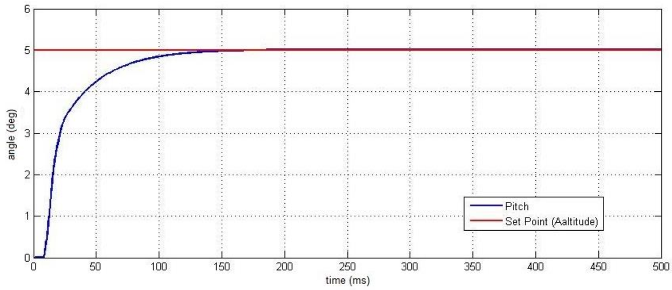
The results of tuning the membership function values on the fuzzy are then applied to the MPPT solar tracker to determine the response and then compared with when using type-1 fuzzy.

3. Results and Discussion

3.1. Solar Tracker uses a Fuzzy Controller

Design of a solar tracker on Photovoltaic using a Fuzzy controller on a dc motor. There are two dc motors used in this control design, namely a dc motor to move the pitch angle and yaw angle on the PV. The results of the system set point test response are then carried out at both angles (Pitch and Yaw) using a fuzzy controller. Fuzzy design has been explained in the previous chapter. Meanwhile, the results of the controller response for pitch angle are shown in Figure 6.

The response resulting from the set point test on altitude-pitch using fuzzy control shows a steady state error value of 0.39% and is able to reach the set point in 0.15 seconds. The response resulting from the set point test on azimuth-yaw using fuzzy control shows a steady state error value of 0.22% and is able to reach the set point in less than 0.3 seconds. From the test results of the pitch angle response and yaw angle response, it shows that the steady state error is small (less than 0.5%) so that the fuzzy control design for this solar tracker system can be implemented and then tested using data from simulations of the sun's position.



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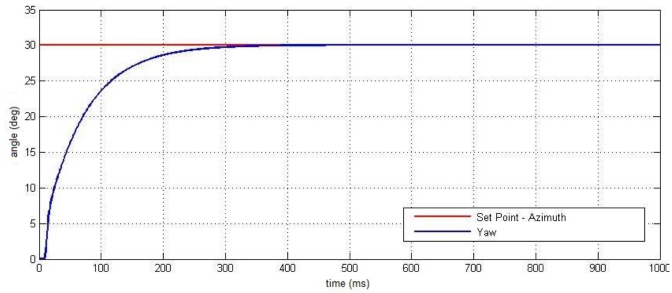

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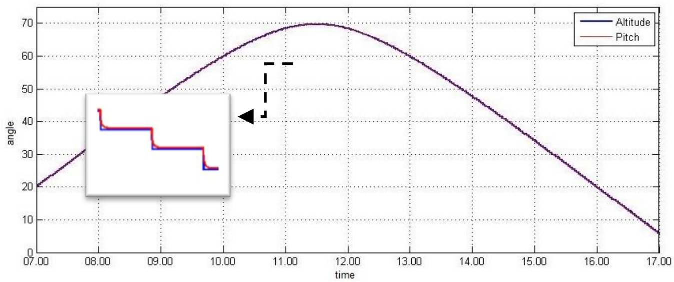
Fig. 6. Angular control response (a) pitch and (b) yaw using fuzzy control

A sun position tracking test was also carried out and the aim was to find out whether the solar panels could follow the sun's position or not. This mechanism aims to optimize the performance of the solar panels so that the power produced is more optimal. The following is the response to the tracking test results of the pitch angle of the solar panel to the altitude angle of the sun as shown in Figure 8 and the yaw angle of the solar panel to the azimuth angle of the sun as shown in Figure 7.



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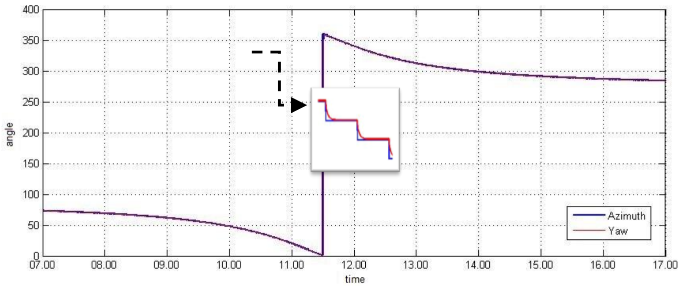

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Fig. 7. Tracking test response (a) altitude-pitch and (b) azimuth-yaw

From the response results given in the image, it can be seen that in the modeling that has been carried out, the solar panels (pitch and yaw angles) can follow the position (altitude and azimuth) of the sun. The azimuth angle response coincides with the yaw angle response and the altitude response is also close to the pitch angle response. So, from the results of the tracking test of the two angles of the sun's position, the fuzzy control design for these two motors can be implemented and then simulated in PV mathematical modeling.

The next performance test was carried out to find out what the response output was from all the solar tracker modeling that had been carried out. Modeling of the solar tracker system was carried out in Simulink Matlab with input in the form of azimuth angle and altitude angle and output in the form of voltage and current as a calculation of the system's output power.

The power output produced by the tracker is greater than that produced by fixed PV. The maximum power produced on the fixed PV is 239.74 W while on the tracker it reaches 247.53 W, meaning that the increase in power for the solar tracker system is 3.25% when compared to the PV output without the solar tracker system. The energy profile of the solar tracker system is shown in Figure 8. If we look at the amount of energy, the amount of energy produced by PV without a solar tracking system is 1,506 J or the equivalent of 0.42 kWh, while the solar tracker is capable of producing 1,767 J of energy. or equivalent to 0.49 kWh, so the energy increase is 14.76%.

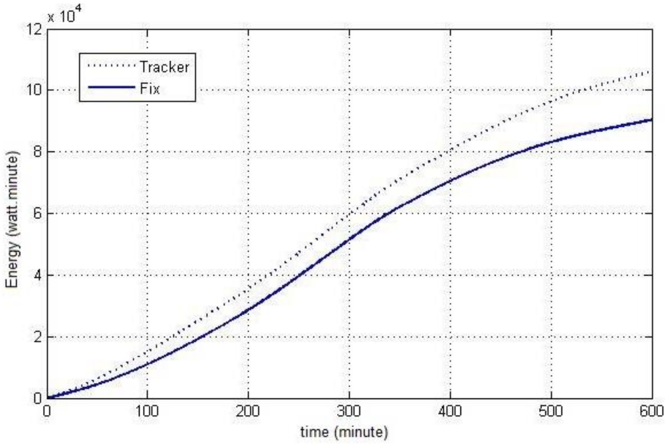
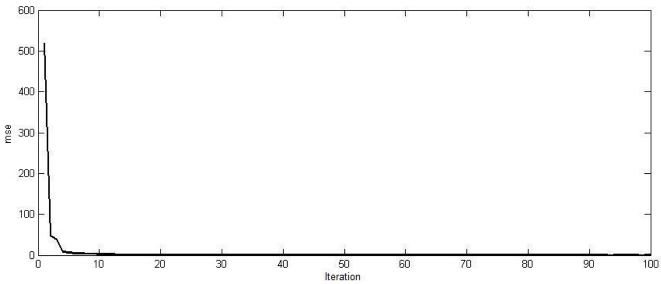


Fig. 8. Energy produced in fixed PV and Tracker

3.2. MPPT Solar Tracker - Photovoltaic using PSO Based Fuzzy Type 2 (FT2PSO)

The output from the solar tracker is further optimized for power using the MPPT mechanism on the solar tracker. Optimization of fuzzy controller parameter values in MPPT using PSO, by getting the smallest MSE (Mean Square Error) value as the objective function. The MSE value will become increasingly convergent as the optimization process progresses. The graph of decreasing MSE value in optimizing Fuzzy input parameters in terms of error and delta error is shown in Figure 9.



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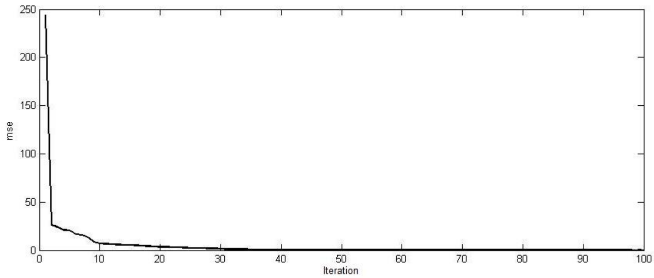

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Fig. 9. MSE at each iteration of input optimization (a) “error” and (b) “delta error” using PSO

The MSE value in the membership function optimization "error" in fuzzy is drastic and will converge in certain iterations. The smaller and faster the convergence of the error value (mse) in the optimization process, the better the optimization results obtained. In the "error" membership function, convergence was formed at the 14th iteration with an mse value of 1,553 and at the 100th iteration it was able to produce a fuzzy "error" membership function parameter which produced an mse of $6{,}935 \times 10^{-13}$.

An almost similar response was also shown when optimizing the "delta error" membership function in drastic fuzzy and would converge in certain iterations. In the "delta error" membership function, convergence was formed at the 34th iteration with an mse value of 0.947 and at the 100th iteration it was able to produce a fuzzy "delta error" membership function parameter which produced an mse of $1{,}799 \times 10^{-15}$.

The optimized membership function error and delta error are then converted into a fuzzy interval of type two with FOU 0.3. The fuzzy type-2 results are then implemented in the solar tracker system to be compared with the system response without using MPPT. The output power of the solar tracker system is able to increase after MPPT is applied to the electricity output. The power increase can reach 520 Watts at the highest power (during the day). When compared with the power on the tracker alone, the increase is 2.18 times. Based on calculation result of the amount of energy, the solar tracker system without MPPT is only capable of producing 1,767 J of energy or the equivalent of 0.49 kWh, while the solar tracker that uses MPPT is capable of producing 7,520 J of energy, or the equivalent of 2.09 kWh. Thus, the addition of MPPT to the solar tracker system can increase the energy produced from the system up to 4.3 times.

4. CONCLUSION

The controller on the solar tracker can use fuzzy with membership functions in the form of error and delta error each amounting to 5, while the controller for MPPT on PV uses PSO based Fuzzy type-2 with a number of membership functions totaling 5. The three fuzzy controls use FIS "sugeno" . In the Photovoltaic system, the power produced by the solar tracker system can increase by 3.25% and the energy increases by 14.76% when compared to the PV-fixed system. The output power of the solar tracker can be further increased using MPPT PSO based Fuzzy type-2, so that the system output power can increase to 759 watts and the energy increases up to 4.3 times.

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