TYPE 2 FUZZY SLIDING MODE CONTROL (T2FSMC) CONTROLLER ON SOLAR PANEL PROTOTYPE USING THE MOST REPRESENTATIVE PARAMETERS

[1]MARDLIJAH, [2]NOORMAN RINANTO, [3]ANNISA RAHMITA S
[1,3]Department of Mathematics

Faculty of Mathematics and Natural Science

Sepuluh Nopember Institut of Technology, Surabaya, Indonesia

[2]Marine's Electrical Engineering Department Shipbuilding

Institute of Polytechnic Surabaya, Indonesia

E-mail: [1]mardlijah@matematika.its.ac.id, [2]noorman.rinanto@gmail.com, [3]annisarahmitas@gmail.com

ABSTRACT

Solar energy is one of alternative energy sources in Indonesia. It can be converted to electrical energy by solar panel. There is a collector in the solar panel for collecting solar energy. The collector can collect solar energy maximally if the position is vertical to the sun. For keeping the collector position is always vertical to the sun, we choose to construct T2FSMC controller because it can control the angular velocity of collector and improve the ability of overcoming the disturbance and uncertainty of solar panel prototype. The controller can be implemented to the solar panel prototype. By using the most representative parameters, we obtain that T2FSMC controller is suitable for the solar panel prototype.

Keywords: *Solar Panel, T2FSMC Controller*

1. INTRODUCTION

Solar energy is a potential energy in Indonesia. It can be developed into an alternative energy because Indonesia has tropical climate. So, it can collect solar energy more than the other countries in the world. The solar energy is converted to the electrical energy by the solar panel.

Solar panel is an energy converter. It converts solar energy to electrical energy. Solar panel consists of solar cells, accumulator, battery, and collector. There is also a solar panel prototype that can be an experimental test tool to obtain the most representative parameters on the mathematical model. It represents the booster of solar panel. The solar energy that is collected by the solar panel must be optimal to obtain the optimal electrical energy. Consequently, the position of collector is kept, so it's always vertical to the sun. If the position of collector, then we can obtain the optimal solar energy [1]. According to the condition, we design a controller that's suitable for the solar panel prototype. It works for setting the angular position of collector. So, it's always vertical to the sun. We notice the angular velocity of collector movement to control it. The controller we construct is T2FSMC.

Type-2 Fuzzy Sliding Mode Control (T2FSMC) controller is a combination of Sliding Mode Control (SMC) and Type-2 Fuzzy Logic (T2FLC) [2]. SMC is one of the robust controllers. It can be applied to the linear system and nonlinear system with uncertainty model and parameter [3]. SMC has a weakness in designing the control system. The designing of control system on SMC is complicated enough. Furthermore, if the value of parameter is down, then there is an error in the control system. T2FLC is a development of Fuzzy Logic Control (FLC). There is a little difference between SMC and FLC. SMC can be applied to the linear system and nonlinear system with uncertainty model and parameter, whereas FLC can be applied to complex linear system with uncertainty that's difficult to model [7,8,9]. By combining the two controllers, we can design Type-1 Fuzzy Sliding Mode Control (TFSMC) controller. TFSMC can't perfectly overcome an uncertainty. So, we need to design T2FSMC that can improve the ability of overcoming disturbance and uncertainty. We construct T2FSMC that's suitable for the solar panel prototype by implementing the most representative parameters to the control system of T2FSMC. They are obtained from an experiment on the prototype solar panel.

On the last research, in 2015, Mardlijah, et all [2] have designed the driven system control of solar panel using T2FSMC. They showed that T2FSMC can be applied on the solar panel system in general (without considering the most representative parameters). Then, in 2016, Sega [5] continued the research by doing an experiment on the solar panel prototype to find the most representative parameters of the solar panel system. By combining the results of their research, we put the parameters which are found by Sega on T2FSMC that's designed by Mardlijah, et all in 2015.

There is some steps we need to obtain T2FSMC controller that's suitable for the solar panel prototype. We have three steps to obtain T2FSMC controller that's suitable for the solar panel prototype. First, we construct the model of solar panel that's given by the last researches. Second, we design SMC to get the sliding surface (S). The last step, we design T2FSMC controller by using the value of u and setting the two membership, S_p and d. On designing T2FSMC, we combine SMC controller and type-2 fuzzy logic (T2FLC). After doing the three steps, we finally doing a simulation by simulink of Matlab. From the result of simulation, we get the angular position that can keep the prototype in order to be vertical to the sun.

In the next section, we first construct the model of solar panel in order to obtain a representative model for the simulation.

2. MODEL OF SOLAR PANEL

A system of DC rotor works on the solar panel prototype as the figure below.

Figure 1: Solar Panel Prototype

The initial model of DC rotor is given [1]:

$$K_m i_a(t) = J\frac{d\omega(t)}{dt} + B\omega(t) \tag{1}$$

with

K_m : torque constant $(N-m/Ampere)$

B : viscous friction coefficient $(N-m/rad/sec)$

J : moment of rotor inertia $(kg-m^2)$

$i_a(t)$: anchor current $(Ampere)$

$\omega(t)$: angular velocity of rotor (rad/sec)

From Equation 1, we obtain:

$$i_a(t) = \frac{J}{K_m}\frac{d\omega(t)}{dt} + \frac{B}{K_m}\omega(t) \tag{2}$$

Then, given the initial equation that represents the amount of voltage's applied to DC rotor:

$$e_a(t) = R_a i_a(t) + L_a\frac{di_{a(t)}}{dt} + e_b(t) \tag{3}$$

$$e_b(t) = K_b\,\omega(t) \tag{4}$$

with

R_a : anchor coil resistance (Ohm)

L_a : anchor coil inductance $(Henry)$

K_b : return emf constant $(Volt-sec/rad)$

e_a : the amount of voltage's applied to DC rotor $(Volt)$

e_b : return emf $(Volt)$

Substitute Equation 2 and 4 to Equation 3, so we obtain:

$$\begin{aligned}
e_a(t) &= R_a\left(\frac{J}{K_m}\frac{d\omega(t)}{dt} + \frac{B}{K_m}\omega(t)\right) \\
&\quad + L_a\frac{d\left(\frac{J}{K_m}\frac{d\omega(t)}{dt} + \frac{B}{K_m}\omega(t)\right)}{dt} + K_b\omega(t) \\
&= R_a\frac{J}{K_m}\frac{d\omega(t)}{dt} + R_a\frac{B}{K_m}\omega(t) \\
&\quad + L_a\frac{d}{dt}\left(\frac{J}{K_m}\frac{d\omega(t)}{dt}\right) + L_a\frac{d}{dt}\left(\frac{B}{K_m}\omega(t)\right) \\
&\quad + K_b\omega(t) \\
&= R_a\frac{J}{K_m}\frac{d\omega(t)}{dt} + R_a\frac{B}{K_m}\omega(t) \\
&\quad + \frac{L_aJ}{K_m}\frac{d}{dt}\left(\frac{d\omega(t)}{dt}\right) + \frac{L_aB}{K_m}\frac{d}{dt}\big(\omega(t)\big) \\
&\quad + K_b\omega(t) \\
&= R_a\frac{J}{K_m}\frac{d\omega(t)}{dt} + R_a\frac{B}{K_m}\omega(t)
\end{aligned}$$

$$+\frac{L_aJ}{K_m}\frac{d^2\omega(t)}{dt^2}+\frac{L_aB}{K_m}\frac{d}{dt}\big(\omega(t)\big)+K_b\omega(t)$$

$$=\frac{L_aJ}{K_m}\frac{d^2\omega(t)}{dt^2}+\left(\frac{R_aJ}{K_m}+\frac{L_aB}{K_m}\right)\frac{d\omega(t)}{dt}+\left(\frac{R_aB}{K_m}+K_b\right)\omega(t) \qquad (5)$$

From Equation 5, we obtain the angular position of DC rotor:

$$\frac{L_aJ}{K_m}\frac{d^2\omega(t)}{dt^2}=e_a(t)-\left(\frac{R_aJ}{K_m}+\frac{L_aB}{K_m}\right)\frac{d\omega(t)}{dt}-\left(\frac{R_aB}{K_m}+K_b\right)\omega(t)$$

$$\frac{d^2\omega(t)}{dt^2}=\frac{e_a(t)-\left(\frac{R_aJ}{K_m}+\frac{L_aB}{K_m}\right)\frac{d\omega(t)}{dt}}{\frac{L_aJ}{K_m}}\frac{-\left(\frac{R_aB}{K_m}+K_b\right)\omega(t)}{\frac{L_aJ}{K_m}}$$

$$\frac{d^2\omega(t)}{dt^2}=\frac{K_m}{L_aJ}e_a(t)-\frac{K_m}{L_aJ}\left(\frac{R_aJ}{K_m}+\frac{L_aB}{K_m}\right)\frac{d\omega(t)}{dt}-\frac{K_m}{L_aJ}\left(\frac{R_aB}{K_m}+K_b\right)\omega(t)$$

$$=\frac{K_m}{L_aJ}e_a(t)-\left(\frac{R_a}{L_a}+\frac{B}{J}\right)\frac{d\omega(t)}{dt}-\left(\frac{R_aB}{L_aJ}+\frac{K_bK_m}{L_aJ}\right)\omega(t)$$

$$=\frac{K_m}{L_aJ}e_a(t)-\left(\frac{R_aJ+L_aB}{L_aJ}\right)\frac{d\omega(t)}{dt}-\left(\frac{R_aB+K_bK_m}{L_aJ}\right)\omega(t) \qquad (6)$$

We know that $\frac{d\omega(t)}{dt}=\dot{\omega}(t)$ and $\frac{d^2\omega(t)}{dt^2}=\ddot{\omega}(t)$.

From Equation 6, we obtain:

$$\ddot{\omega}(t)=\frac{K_m}{L_aJ}e_a(t)-\left(\frac{R_aJ+L_aB}{L_aJ}\right)\dot{\omega}(t)-\left(\frac{R_aB+K_bK_m}{L_aJ}\right)\omega(t) \qquad (7)$$

From Equation 3, we see that the control input of solar panel system is the amount of voltage's applied to DC rotor $\big(e_a(t)\big)$. In the other word, we can denote $e_a(t)$ as the control input u. Let $C=\frac{K_m}{L_aJ}$, $D_1=\frac{R_aB+K_bK_m}{L_aJ}$ and $D_2=\frac{R_aJ+L_aB}{L_aJ}$. So, Equation 7 becomes:

$$\ddot{\omega}(t)=Cu-D_2\dot{\omega}(t)-D_1\omega(t) \qquad (8)$$

The advantage of T2FSMC is able to imptove the ability of overcoming an uncertainty and disturbance. So, we add a disturbance, $d(t)$. From Equation 8, we obtain:

$$\ddot{\omega}(t)=Cu-D_2\dot{\omega}(t)-D_1\omega(t)+d(t)$$

or

$$\ddot{\omega}=Cu-D_2\dot{\omega}-D_1\omega+d \qquad (9)$$

Equation 9 is a mathematical model that's used on Simulink of Matlab in the solar panel case.

For applying the equation into Simulink of Matlab, we need parameters that have the most representative output to the booster of solar panel prototype. By doing an experiment, Sega [5] gets the parameters. It is done four times by giving some variations of input voltage. They are $4V$, $5V$, $6V$, $7V$, $8V$, $9V$, $10V$, $11V$, $12V$ and $13V$. Moreover, we also give four different values of torque constant K_m and return emf constant K_b. The result of simulation shows that the third simulation has obtained the parameters we need.

In the third simulation, we get the trust level of solar panel prototype. It reaches 0,97317587123. Furthermore, we also get the values of anchor coil resistance (R_a), anchor coil inductance (L_a), return emf constant (K_b), torque contant (K_m), moment of rotor inertia (J), and viscous friction coefficient (B). R_a is 18,2214 ohm, L_a is 0,00866 $Henry$, K_b is 0,030941093 $volt\ sec/rad$, K_m is 0,030941093 $N-m/Ampere$, J is 0,000090 $kg\ m^2$ and B is 0,000025 $N-m/rad/sec$.

We have obtained the representative model for simulation by Equation 9, so we do the second step to get the sliding surface (S). The detail of the step is shown on the section below.

3. DESIGN OF SLIDING MODE CONTROL (SMC)

After obtaining the parameters, we design T2FSMC. Before designing it, we first design a SMC controller. We design a sliding surface. So, the trajectory can slide to the sliding surface. We need a boundary layer in designing SMC. It's used to keep the position of trajectory. So, it's always around the center point. The boundary layer also works for pressing the chattering.

For designing SMC controller, we first need to set an input for SMC. In the case, we control the angular position of solar panel. Solar energy that's collected by the solar panel, can reach an optimal value if the position of solar panel is vertical to the sun. According to the condition, the input must be the angular velocity (ω_d). Therefore, we can find the error of SMC controller:

$$e = \omega - \omega_d \qquad (10)$$

From the error above, we can also find the difference of error:

$$\dot{e} = \dot{\omega} - \dot{\omega_d}$$

and

$$\ddot{e} = \ddot{\omega} - \ddot{\omega_d}.$$

The rotation system of earth has no an angular acceleration. So, the angular velocity (ω_d) is always fixed. In the other words, $\dot{\omega_d} = \ddot{\omega_d} = 0$, so we get $\dot{e} = \dot{\omega}$ and $\ddot{e} = \ddot{\omega}$.

Next step, we construct a switching function to get the sliding surface:

$$S = \dot{e} + \lambda e \qquad (11)$$

with λ is an arbitrary positive constant $(\lambda > 0)$. By substituting Equation 10 and $\dot{e} = \dot{\omega}$ to Equation 11, we obtain:

$$S = \dot{\omega} + \lambda(\omega - \omega_d) = \dot{\omega} + \lambda\omega - \lambda\omega_d.$$

Then, we find the difference of switching function:

$$\dot{S} = \ddot{\omega} + \lambda\dot{\omega} - \lambda\dot{\omega_d}. \qquad (12)$$

We have obtained that $\dot{\omega_d} = 0$. It's because the rotation system of earth has no an angular acceleration. So, Equation 12 becomes:

$$\dot{S} = \ddot{\omega} + \lambda\dot{\omega}. \qquad (13)$$

Substitute Equation 9 to Equation 13:

$$\begin{aligned}\dot{S} &= Cu - D_2\dot{\omega} - D_1\omega + d + \lambda\dot{\omega}\\ &= Cu - D_1\omega - (D_2 - \lambda)\dot{\omega} + d. \qquad (14)\end{aligned}$$

From Equation 14, we have designed the sliding surface that we use to get the two membership functions of T2FSMC. Then, we construct T2FSMC controller. The steps for designing T2FSMC is almost principally same with TFSMC. The difference between two controllers is on the type of fuzzy that's used. We need the two membership functions to design T2FSMC. The steps to get them is shown in the next section.

4. DESIGN OF TYPE 2 FUZZY SLIDING MODE CONTROL (T2FSMC) CONTROLLER

TFSMC uses type-1 fuzzy logic. Whereas, T2FSMC uses type-2 fuzzy logic (T2FLC). T2FLC has 3 types of membership functions. They are the foot print of uncertainty (FOU), upper membership function (UMF) and lower membership function (LMF) [4].

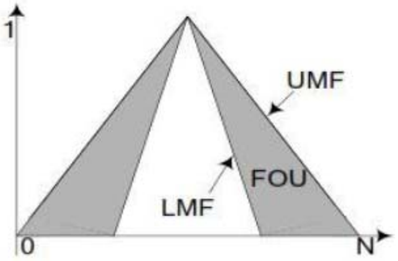

Figure 2: Membership Functions of T2FLC

Operation of T2FLC is similar to type-1 fuzzy logic. It's used by two functions of type-1 fuzzy logic [8].

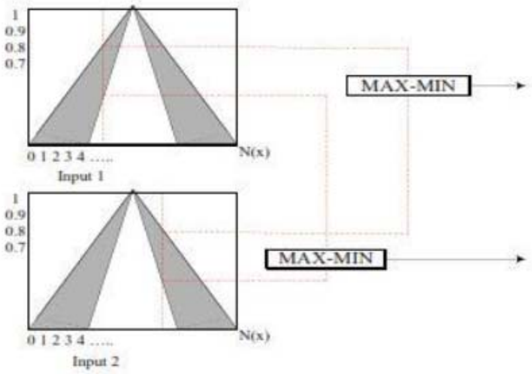

Figure 3: Operation of T2FLC

The structure of type-2 fuzzy logic is similar to the structure of type-1 fuzzy logic. It is consists of process fuzzifier, rule bases, inference and defuzzifier. The difference between the structure of type-1 and type-2 FLC is on the output of processor. The type-reducer and defuzzifier in T2FLC are the main part of the output processor. They generated a type-1 fuzzy set output (from the type-reducer) or a crisp number(from the defuzzier) [6].

In the section 3, we have designed the SMC. By combining SMC and T2FLC, we get T2FSMC. T2FSMC has two inputs variable. They are from SMC and T2FLC. After we input the variables into the plant of T2FSMC, we obtain the output of type-2 fuzzy. The output is as control law to the plant. The scheme of T2FSMC is given in Figure 4 [10].

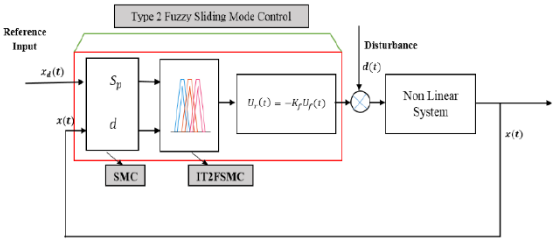

Figure 4: T2FSMC Scheme

From the scheme, there are two variable inputs, the state vector ($x(t)$) and the desired state vector ($x_d(t)$). After we input the variables into type-2 fuzzy rules, we get a control of the plant ($U_r(t)$). The control is used by the solar panel prototype for controlling the plant from disturbance ($d(t)$). There is an error in the plant if we add a disturbance on it. The error is processed to have a small value by T2FSMC.

T2FSMC designs work as well as SMC. It also uses a sliding surface (S). Thus requiring switching function to determine the control law as an input to the plant. Control law in T2FSMC is obtained from rules fuzzy [10]:

$$R^i\text{: if } S_p = \tilde{S}^i \text{ and } d = \tilde{D}^i\text{, then } u = \tilde{U}^i\ ,$$
$$i = 1, \ldots, M$$

where R^i is fuzzy rules i-th, $\tilde{S}^i$= **FS** and $\tilde{D}^i$= **FD** are fuzzy values for membership functions S_p and d in fuzzy range i-th and $\tilde{U}^i$ is the result of input range i-th that corresponded of fuzzy space.

T2FSMC has the two membership functions, S_p and d. The values of them are represented as an interval. It causes overcoming ability an uncertainty and disturbance. It is different from TFSMC. It has two membership functions, S_p and d, which the values of them are fixed values. It means that they're not values where are in an interval. So, the controller isn't perfectly able to overcome an uncertainty and disturbance. The membership function S_p shows distance between points of state and sliding surface. Whereas the membership function d shows distance between points of state and the normal line of sliding surface through the origin of field. The illustration of S_p and d is shown by Figure 5 [10].

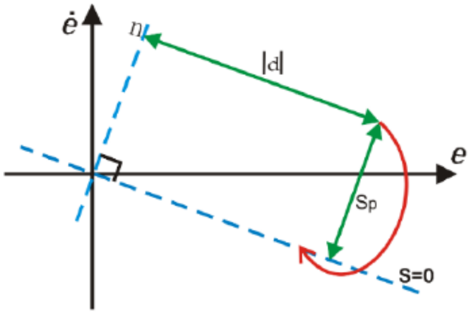

Figure 5: Illustration of S_p and d

According to the condition, we design the two membership functions on T2FSMC by setting the membership interval of e and $\dot{e}$. We get it by observing the movement of solar panel prototype.The experiment that we do for collecting the solar energy optimally is about 12 hours in a day by using the solar panel prototype. It means that the solar panel prototype has been used for 43.200 secons in a day. It moves from the left side to the right side for collecting the solar energy. In the other words, the angular position of it is 180° or $\pi\ rad$ =3,14.

From the result of experiments, we obtain a setpoint. It's $\frac{3{,}14}{43200} = 0{,}000073$. The setpoint represents the angular velocity (ω). It can be a guide point of input for T2FSMC controller. In Equation 10, the error is defined as difference between ω and ω_d. Even the movement of error is defined as difference between $\dot{\omega}$ and $\dot{\omega}_d$. By observing the opened loop of solar panel prototype, we can determine the membership interval e and $\dot{e}$:

$$e \in [-0.000073, 0.0015]$$
$$\dot{e} \in [-0.000087173, 0.0014].$$

We have obtained the membership interval e and $\dot{e}$. After that, we're looking for the maximum value of the two membership functions, S_p and d. They're input for T2FSMC. Defined S_p and d as follows:

$$S_p = \frac{\dot{e}+\lambda e}{\sqrt{1+\lambda^2}}. \tag{15}$$

$$d = \sqrt{|e|^2 - {S_p}^2}. \tag{16}$$

We choose the maximum error of the interval error because we want to get the maximum value of S_p and d. So, Equation 15 becomes:

$$S_p = \frac{0.0014+10(0.0015)}{\sqrt{1+10^2}} = 0.0016.$$

After that, we also get the value of d by substituting $S_p = 0.0016$ to Equation 16:

$$d = \sqrt{(|0.0015|^2 + 0.0014^2) - 0.0016^2}$$
$$= 0.0013.$$

We have obtained the value of S_p and d. They're 0.0016 and 0.0013. So, we can determine the interval of S_p and d:

$$S_p \in [-0.0016, 0.0016]$$
$$d \in [0, 0.0013].$$

We need a large range of S_p and d to obtain the best result of simulation. So, we enlarge the value of d. It becomes $d \in [0, 0.0015]$. The design of simulink for obtaining the value of S_p and d as follows:

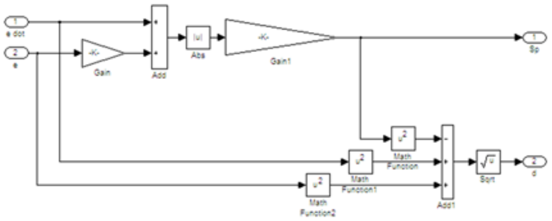

Figure 6: Calculating the Value of S_p and d

Next, we set the input for T2FSMC controller by designing the two membership functions, S_p and d. We use trial and error method then moving them until we get the result we want. Considering the interval of S_p and d, so we can get the two membership functions, S_p and d:

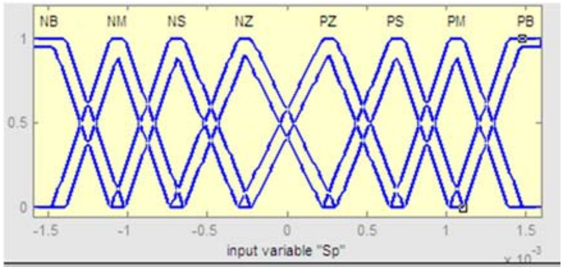

Figure 7: Membership Function of T2FSMC (S_p)

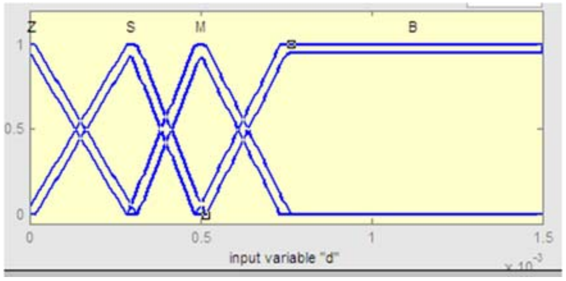

Figure 8: Membership Function of T2FSMC (d)

We also set the control input (u) for T2FSMC controller. It depends on the capability of DC rotor. In the simulation, we design u as follows:

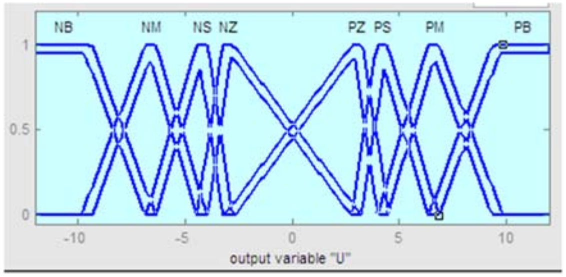

Figure 9: Control Input of T2FSMC

After that, we do a simulation for T2FSMC by setting the gains. The simulation is presented on the next section.

5. SIMULATION OF T2FSMC CONTROLLER

For doing a simulation for T2FSMC, we need gains. There is three gains in the simulation. They are gain 1, gain 2 and gain 3. To get the result we want which the graph of angular velocity of solar panel prototype moves to the setpoint, 0.000073, so we use the trial and error method. We get the value of three gains. The gain 1 is 0.0000001. The gain 2 is 0.00005. The gain 3 is 0.022945. The figure below is the simulation of T2FSMC controller that can be applied to the solar panel prototype:

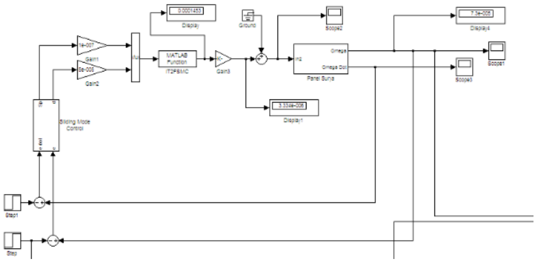

Figure 10: Simulation of T2FSMC

According to the concept of T2FSMC controller, the controller can improve the ability of overcoming a disturbance. So, we design a disturbance on the simulation in an interval of time, from 17th time until 21th time. The value of disturbance is $0.00000001\ rad/s$. The design of disturbance is shown by Figure 11.

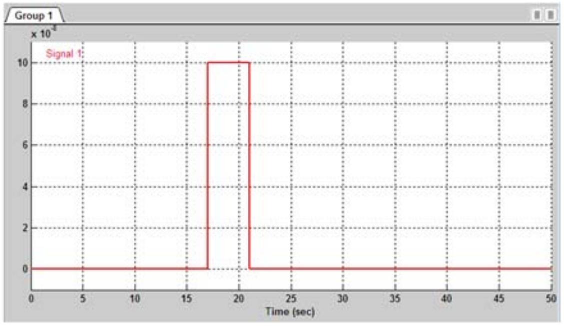

Figure 11: Disturbance of T2FSMC

In the real condition, the disturbance is represented as something which can give shocks on solar panel prototype. It can be wind, intensity of sunlight and interference of DC rotor machine.

After designing the disturbance, we do simulation again to prove that T2FSMC controller can improve the ability of overcoming the disturbance. The simulation of T2FSMC controller with the disturbance is shown below.

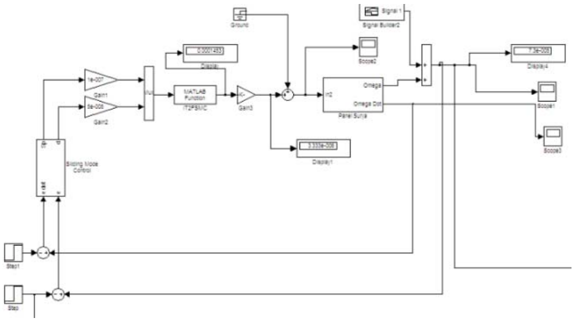

Figure 12: Simulation of T2FSMC with Disturbance

From the simulation, we get the result of it. In the next section, we analyze the result of simulation.

6. ANALYZE THE RESULT OF T2FSMC SIMULATION

The result of simulation shows that the graph of angular velocity of solar panel prototype moves to the set point and is stable on it. We can see the graph from the figure below.

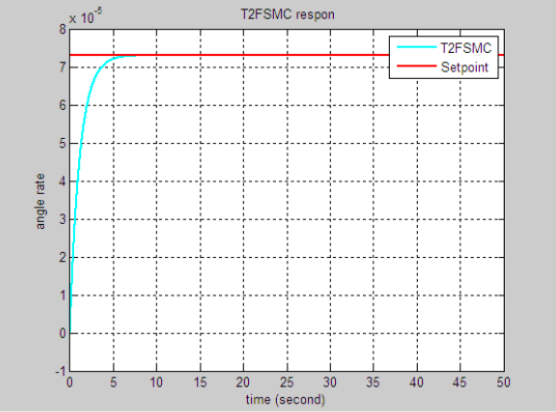

Figure 13: Result of T2FSMC Simulation

In the simulation, the setpoint represents a stability point of the solar panel movement. So, we can control the movement of solar panel prototype by the set point. The graph of angular velocity of solar panel prototype moves to the set point and is stable on it in 6.78th time (second). From the graph on Figure 13, there is no overshoot on the system of solar panel. It proves that T2FSMC controller can control the system. From Figure 13, we can also see that the optimal angular velocity of solar panel is on the set point. It means that T2FSMC controller is suitable for the solar panel prototype.

By designing a disturbance, we get the result of T2FSMC simulation with disturbance. On Figure 14, we know that T2FSMC controller can make the graph of angular velocity of solar panel prototype moves to the set point and is stable on it even after we add a disturbance on the simulation. Although there is an overshoot on T2FSMC simulation with disturbance, the graph of angular velocity of solar panel prototype can move back to the set point in 23.77th time (second) and is stable on the setpoint. It means that the robustness of T2FSMC can be represented by Figure 14. It shows the advantage of T2FSMC controller to improve the ability of overcoming a disturbance.

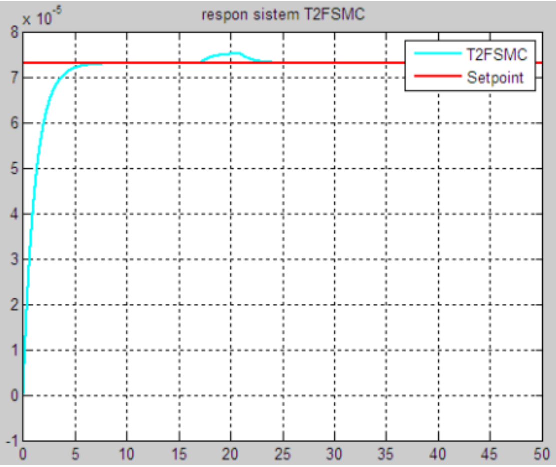

Figure 14: Result of T2FSMC Simulation with Disturbance

Basically, the purpose of simulation is obtaining the value of angular position (θ). By setting an integrator on the plant of T2FSMC system, we can get it. The value of angular position is shown by Figure 15.

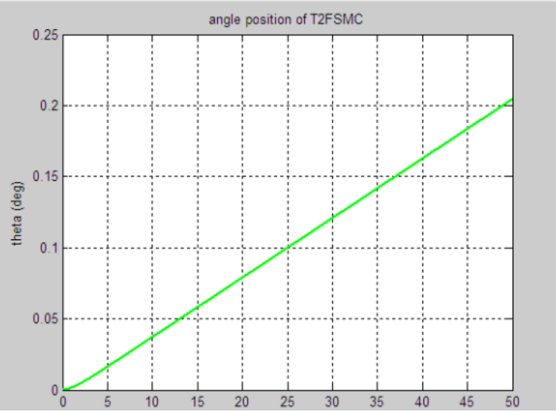

Figure 15: Angular Position of Solar Panel Prototype

From Figure 15, we know that the optimal angular position is about 0.2 degree in 50 seconds. It's obtained from the angular velocity on Figure 13 that's through the set point. It means that the stable position of solar panel is in the set point. In the other word, the prototype can maximally collect the solar energy if the position is about 0.2 degree in 50 seconds. In order to be easier for validating the result of simulation (the angular position in degree) with the angular position of solar panel prototype, the value of angular position on the simulation is changed to be radian units. The value of angular position which's shown by Figure 15 becomes about $3.5 \mathrm{x} 10^{-3}\ rad$. If the running time of simulation more than 50 seconds, the result of the angular posititon must be the same with the angular position of the real solar panel prototype in the experiment.

We obtain the result of T2FSMC simulation as Figure 14 and 15 using trial and error method for choosing the gains which are suitable for the solar panel system. It's better to find an effective method for obtaining the gains which are suitable for the system.

7. CONCLUSION

According to the simulation, we get the result that the set point that's obtained from the experiment on the solar panel prototype is suitable with the T2FSMC controller. The controller can reach the set point and is stable on it although we add a disturbance on the simulation. From the stable angular velocity, we get the angular position that's optimal to collect the solar energy. By using the most representative parameters, T2FSMC controller is suitable for the solar panel prototype.

ACKNOWLEDGEMENTS

We sincerely thank to Research and Society Perpetuation Directorate of Research, Technology, and Higher Education Ministry who give fund for this research.

REFERENCES

[1] Iswanto, W, “Perancangan dan Simulasi Sistem Kontrol Posisi pada Panel Surya dengan Menggunakan Metode Fuzzy Sliding Mode Control (FSMC)”, *Final Project Sepuluh Nopember Institut of Technology*, 2010.

[2] Mardlijah, Subiono, Sentot DS and Yahya Efprianto, “On Designing of the Driven System Control of Solar Panels Using Type 2 Fuzzy Sliding Mode Control (T2FSMC)”, *Paper Sepuluh Nopember Institut of Technology*, 2015.

[3] Rizan, Rifqi Izzatur, “Analisis dan Perancangan Sistem Pengendali pada Inverted Pendulum Menggunakan Metode Fuzzy Sliding Mode Control”, *Final Project Sepuluh Nopember Institut of Technology*, 2008.

[4] C, Oscar, “Type-2 Fuzzy Logic in Intelligent Control Applications”, *Springer: German*, 2011.

[5] Prandita, Sega, “Identifikasi Parameter Model Matematika Pada Penggerak Prototype Panel Surya”, *Final Project Sepuluh Nopember Institut of* Technology, 2016.

[6] Abadi,I,"Kombinasi Dual Tracking Method Pada penjejak Matahari Dua Sumbu Dengan Kontrol Logika Fuzzy Berbasis Particle Swarm Optimization", *Dissertation Sepuluh Nopember Institut of Technology*, 2016.

[7] Mardlijah, Jazedie, A., Santoso, A. and Widodo, B, "A New Combination Method of Firefly Algorithm and T2FSMC for Mobile Inverted Pendulum Robot", *Journal of Theoretical and Applied Information Technology 47, 2*, 2013.

[8] Mardlijah, Abdillah, M., Jazedie, A., Santoso, A. and Widodo, B, "Performance Enhancemet of Inverted Pendulum System by Using Type 2 Fuzzy Sliding Mode Control (T2FSMC)", *International Conference of Electrical Engineering and Information*, 2011.

[9] Mardlijah, Jazedie, A., Widodo, B., Santoso, A. and Abdillah, M, "Design og T2FSMC Controller with Manimum Gain Scale Factor by Optimizing Membership Function Using FireFly Algorithm on Mobile Inverted Pendulum", *International Review of Automatic Control (I.RE.A.CO.) 6, 4*, 2013.

[10] Ming-Ying Hsiao, Tzuu-Hseng S. Li, J.-Z. Lee, C.-H. Chao and S.-H. Tsai, "Design of interval type-2 fuzzy sliding-mode controller" *Information Sciences.Volume 178, Issue 6*, 2008, Pages 1696–1716.

[11] Jeng-Nan Juang and R. Radharamanan, " Design of a Solar Tracking System for Renewable Energy", *Proceeding of 2014 Zone 1 Conference of the American Sosiety for Engineering Education*, 2014.