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INCREASING PHOTOVOLTAIC PLANTS POWER USING PID CONTROLLER DESIGN

Increasing photovoltaic plants power using pid controller design

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Resumen: El sistema fotovoltaico (PV) es un sistema que proporciona electricidad a partir de la energía solar. En este sistema, la generación directa de electricidad se realiza mediante células solares. La célula solar, siendo semiconductores, está hecha de silicio, el segundo elemento común en la corteza terrestre. Cuando se brilla solar a la superficie de la célula fotovoltaica, se genera un potencial diferente entre los electrodos positivo y negativo y, por lo tanto, se lleva a cabo una corriente y se puede almacenar la energía resultante. El seguimiento del punto de potencia máximo es un algoritmo en los controladores de carga que se utiliza para alcanzar la máxima potencia posible desde el módulo fotovoltaico. El voltaje en el que PV puede entregar la potencia máxima se llama punto de potencia máxima. La potencia máxima cambia con la radiación, la temperatura ambiente y la temperatura de la celda. El uso de un controlador inteligente es una de las maneras de lograr el máximo punto de potencia. En este trabajo se investiga el seguimiento del punto de potencia máxima de la matriz fotovoltaica utilizando un controlador inteligente y diseñando un controlador PID.

Palabras clave: Planta fotovoltaica, potencia máxima, controlador PID

Abstract: Photovoltaic (PV) is system that provides electricity from solar energy. In this system, direct generation of electricity is provided using solar cells. Solar cell, being semiconductors, are made of silicon, the second common element in earth crust. When there solar is glinted to the surface of PV cell, potential different is generated between positive and negative electrodes and therefore a current is carried out and resulted power can be stored. Maximum power point tracking is an algorithm in charge controllers that is used for attaining maximum possible power from PV module. Voltage in which PV can deliver the maximum power is called maximum power point. Maximum power changes with radiation, environment temperature and cell temperature. Using an inteligent controller is one of the ways for achieving maximum power point. In this paper maximum power point tracking of PV array is investigated using intelligent controller and designing a PID controller.

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Keywords: Photovoltaic plant, maximum power, PID controller

1. INTRODUCTION

Main element of photovoltaic technology is solar cell. PV cells that are generally known as solar cells, are made of solid semiconductor materials. Silicon is a very common element that is widely used due to its abundance in PV cells. However silicon is an abundant element and covers a high percentage of the earth crust, they are highly priced because of the process of fabrication and purification.

Photovoltaic cells produce electricity by using solar radiation and solar cells, and by creating a differential electrical pressure in properly constructed semiconductors. Today, the most effective and cheapest solar cell is a substance called silicon. When the sun shines to a photovoltaic cell, it gives the electrons more energy. Nowadays, humans have become increasingly in need of energy due to scientific advances in various fields. This has forced them to get the required energy in various ways.

At the same time, the main problem in the production of energy in the traditional way is the environmental pollution and shortages in energies generated by fossil fuels. Therefore, it is inevitable for humanity to look into new sources of energy that are both incalculable and non-contaminated. One of the energies that has been very attractive for humans for many years is the endless energy of the sun (Nehrir M.H., C. W 2009).

To maximize the efficiency of a solar system, a system is required that places photovoltaic panels in the direction of direct sunlight, called the solar tracking system. There should also be an electrical system capable of placing photovoltaic panels at an appropriate operational point with the maximum transient power. However, there are problems with placing solar panels at the maximum power point, including non-linearity of the solar cell output curve as well as its variability with light and temperature changes. Therefore, a controller system for photovoltaic cells should be considered, which, in addition to placing the cell at the best operational point, if this point is changed due to the weather conditions, still rapid tracking of the maximum point of the system's transient power at optimal point would be possible. This kind of continuous finding and tracking is called maximum power point tracking.

The basic discipline for tracking the maximum power point is to extract the maximum power from the photovoltaic module by adjusting its working voltage level, meaning that MPPT compares the output of the photovoltaic module with the battery voltage, then the best power for charging the battery is produced. Therefore, for optimal performance of the module and its high efficiency, photovoltaic cell control for achiving maximum power is of great importance. Maximum power point tracking has been carried out by various methods. The constant voltage algorithm is based on the fact that the maximum power point voltage changes a little with radiation. The main disadvantage of this method is the loss of energy when the load is not connected to the grid (Zhihao, &Xiaobo 2009).

The turbidity and monitoring method is the most commonly used method for tracking the maximum point voltage (V_{MP}) based on the turbulence of the array's operating voltage and observation of dP/dt. The derivative direction is indicative of too high or low voltage, and also the fact that for achieving V_{MP} and making dP/dt equal to zero, voltage must be increased or decreased (Esram & Chapman, 2007). In the climbing the hill with turbulent duty ratio technique, the power converter, current converter and followed by the array voltage disturbs and just like before, dP/dt is observed. The above techniques are not suitable for rapid atmospheric variations (Sara 2006). In parasitic capacitance capacity, there is a parasitic capacitance in each cell that is used to determine the maximum power point. This technique uses a switching ripple to disturb the array (Hohm &Rop (2000).

In ripple correlation control method, by connecting a photovoltaic array to a power converter, the switching operation of the converter generates a ripple in voltage and current. As a result, the power of the array is also influenced by Ripple (Bazzi, & Karaki, 2008). Over the past decade, microcontrollers have made it increasingly popular to use fuzzy logic control for MPPT. In this method, E and ΔE are usually inputs of the controller, and its output is ΔD, or the power cycling changes of the power converter (Veerachary M, Senjyu, Uezat 2003).

2. PHOTOVOLTAIC SYSTEM

INTRODUCTION AND ITS PRINCIPALS

An ideal solar cell is modeled as a parallel current source with a diode. But there is no ideal solar cell. Therefore, in order to model a solar cell, in addition to the current source and diode, the series and parallel resistors are added to the model. Maximum Power Point tracking is a method for maximizing the power of photovoltaic systems. Photovoltaic systems are used in various ways. In most common applications, the power generated by solar panels is converted to alternating current by the inverter and connected directly to the grid. Photovoltaic systems have low efficiency due to their output power variability. Maximum power point tracking algorithms play an important role in optimizing solar efficiency in these systems. The PV system efficiency can be improved by optimizing the output voltage of the PV array. Also, by introducing an improved model of a sample silicon cell to optimize the maximum power capability in any atmospheric conditions, optimization algorithm can be used. In this way, using optimization methods such as fuzzy, neural, genetic,… data are trained. The results obtained from these methods indicate the accuracy and speed of the proposed method in maximum power tracking and also increasing PV array efficiency. A photovoltaic system with maximum power point tracking as controller is as follows:

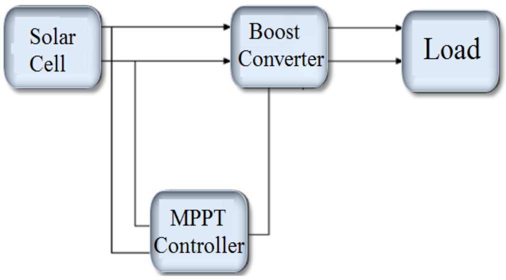

Figure 1: Photovoltaic system with controller

3. TYPE-2 FUZZY CONTROLLER DESIGN

Designed fuzzy controller has two inputs and three outputs. Inputs are errors and errors changes and outputs are controller parameters changes (ΔK_P, ΔK_I, ΔK_D). Inputs and outputs are below seven sebset:

{NB, NM, NS, Z , PS, PM, PB}

These subsets indicates below words:
Negative Big, Negative Middle, Negative Small, Zero, Positive Small, Positive Middle, Positive Big

Numerical ranges of input and output variables of the system are as follows:

{-3,-2,-1,0,1,2,3}

Type-2 fuzzy controller parameters rules are as defined in the following tables:

Table 1. ΔK_P rules

de / ΔK_P / e	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. ΔK_I rules

de / ΔK_I / e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. ΔK_D rules

de / ΔK_D / e	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Acording to these rules, mamdani algorithm is used for Inference. As explained before, controller's outputs are controller parameters changes, therefore type-2 fuzzy controller parameters are calculated as below:

$$K_P + \Delta K_P \ , \ K_I + \Delta K_I \ , \ K_D + \Delta K_D$$

For input and output variables, the Gaussian type-2 :membership functions are considered as follows

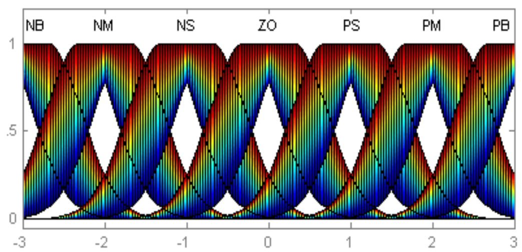

Figure 2: membership function of input and output variables

4. INTRODUCTION OF SYSTEM UNDER STUDY AND APPLYING THE CONTROLLER

Photovoltaic system simulation in based on the electrical model of Fig. 3 and equations are as follows:

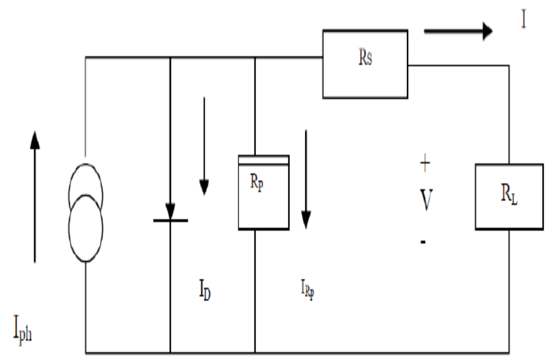

Figure 3. Equivalent circuit of solar cell

$$I_{ph} = I_D + I_{R_p} + I \quad (1)$$

$$I = I_{ph} - I_D - I_{R_p} \quad (2)$$

$$I = I_{ph} - I_o.\left[\exp\left(\frac{V+I.R_s}{V_T}\right) - 1\right].\left[\frac{V+I.R_s}{R_p}\right] \quad (3)$$

Below parameters are defined:

I_{ph}: Radiation current

I: Cell current

I_o Reverse saturation current

V: Cell voltage

R_s:: Series resistor

R_p: Parallel resistor

V_T :Thermal voltage $(\frac{KT}{q})$

K: Boltzmann's Bolt

T temperature (K)

q: The charge of an electron

$$I = n_p I_{ph} - n_p I_{rs}\left[\exp\left(\frac{q}{KTA} * \frac{V}{n_s}\right) - 1\right] \quad (4)$$

$$I_{rs} = I_{rr}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_G}{KA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \quad (5)$$

$$I_{ph} = [I_{scr} + K_i(T - T_r)]\frac{S}{100} \quad (6)$$

$$P = IV = n_p I_{ph} V\left[\left(\frac{q}{KTA} * \frac{V}{n_s}\right) - 1\right] \quad (7)$$

I : Output current of PV array

V: Output voltage of PV array

n_p: Number of parallel cells

n_s: Number of series cells

q: The charge of an electron

K:: Boltzmann's Bolt

A: P-N bond ideality factor

T: Cell temperature (K)

I_{rs}: Reverse saturation current

I_{rr}: Reverse saturation current in Tr

E_G: The semiconductor gap used in the cell

I_{scr}: Short circuit current at reference temperature and radiation

K_i: Short circuit flow temperature coefficient

S: Solar radiation $(\frac{mW}{cm^2})$

Boos converter is simulated based on model of Fig. 4 [8]:

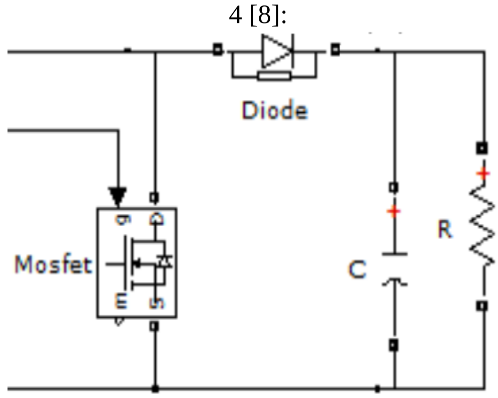

Figure 4. Boost converter

Photovoltaic system is simulated according to Fig. 5:

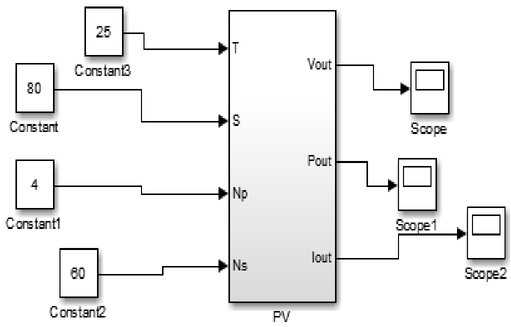

Figure 5. Photovoltaic array

Photovoltaic array simulation model details are as follows:

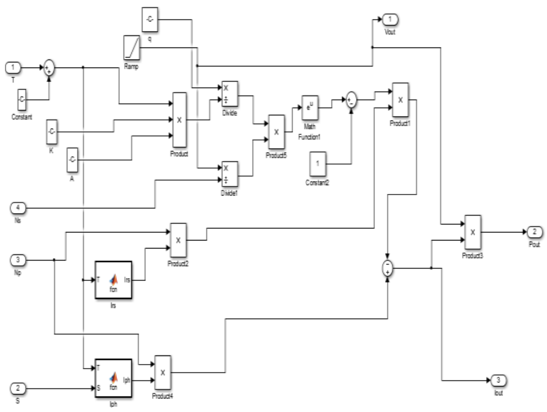

Figure 6. Photovoltaic array simulation model details

According to the above explainations, whole system is simulated as Fig. 7:

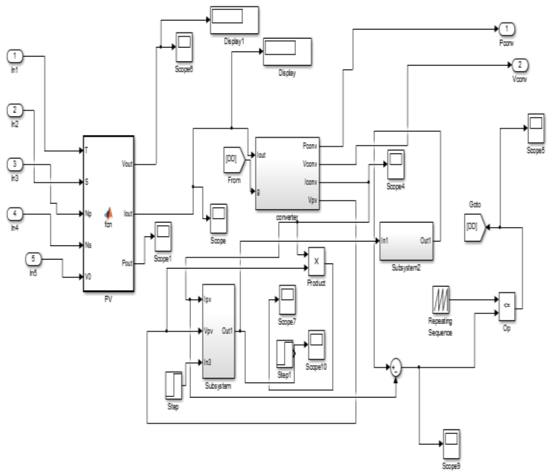

Figure 7. Whole photovoltaic simulation system

5. RESULTS

Different controllers were applied to the photovoltaic system and the following results were obtained. The effect of type-2 fuzzy controller on the photovoltaic system is shown in T = 50 and S = 80 conditions and compared with fuzzy PID and PID controllers. As can be seen from Figs. 8 and 9, power tracking has overshoot. This overshoot causes serious risks to industrial equipment. In Figure 9, the system is able to receive maximum power at the instant of 0.1, but this can cause the system to not operate under the nominal conditions and uses the maximum capacity of the device. In Figure 10, the overshoot is zero and tracking is excellent. Also, timing is perfect, which has reached its final value in 0.01 seconds, therefore it has a particularly low latency. Also, Table 4 shows the comparison of power generation, which indicates that type 2 fuzzy controller will have the best steady power.

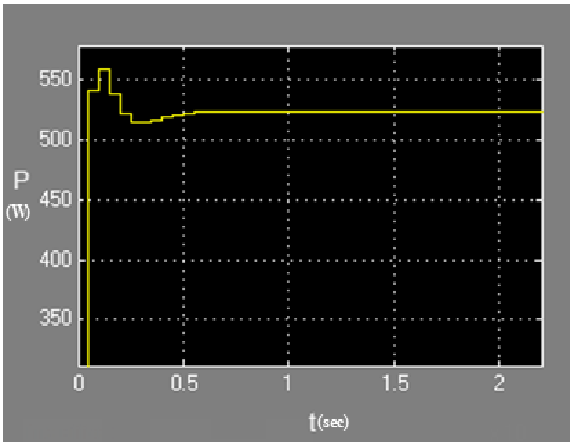

Figure 8. Output power of photovoltaic system with PID controller

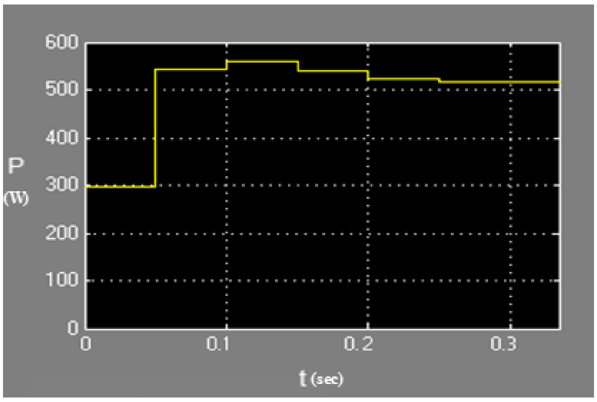

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Figure 9. Output power of photovoltaic system with fuzzy PID controller

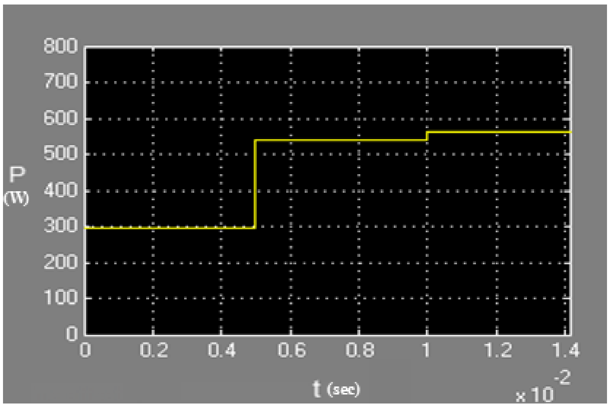

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Figure 10. Output power of photovoltaic system with type-2 fuzzy PID controller

Table 4. Comparison of produced power (W)

Controller type	Steady Power	Maximum Power
PID	523	568
F-PID	518	560
F2-PID	561	561

6. CONCLUSIONS

This paper focuses on tracking the maximum power point with fuzzy type-2 PID controller. In control of a system, the stability and system's speed to reach the stability are of great importance and most control methods are also used for these purpose in various systems. The more the system outputs are without oscillation and overshoot reaches to its final value, the system efficiency will be higher. So, with this in mind, the effects of different controllers on this system can be compared. When the PID controller is used, the output power with oscillation and overshoot reaches its final state. This oscillation is reduced by using a fuzzy PID controller, and the system is faster at its final power. The best mode was when using fuzzy type-2 PID controller. In this case, as was shown, it is clear that the overshoot of the system has completely disappeared and the system has reached its steady state at a very high speed.

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