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# Analysis of the Effect of N719 Dye Concentration and Anode Soaking Time on the Performance of DSSC Using Fuzzy Analysis

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**ABSTRACT**

Dye sensitized solar cells has been considered as an alternate to silicon solar cell owning to their low cost and easy manufacturing. A dye-sensitized solar cell uses dye as a charge generation source. When light falls on the dye an electron hole pair is generated. Commonly used dye is Ruthenium (N719). The prepared anode (Usually metal oxide) is dipped in a solution of ruthenium dye and then the cell is stacked. Dye plays an important role in the overall efficiency of the cell. In this work, a parametric estimation using MATLAB Fuzzy analysis on the concentration of ruthenium dye and time for which the anode is dipped in the dye is analyzed and its effect on the overall power conversion efficiency of the cell is studied. The result depicts an increase in power conversion efficiency with increase in the concentration for dye. However, more time for anode dipping shows a reduction in efficiency which represent inverse relation between anode dipping time and performance of N719 dye. Less than 1% error between the simulation and calculated results of Fuzzy analysis shows the accuracy of the system.

**Keywords:** Dye sensitized solar cell; Fuzzy analysis; Dye; Ruthenium.



## Introduction:

Solar photovoltaic are considered an as emerging research domain owning to its clean energy output as compared to the conventional resources. Some of the common advantages of solar photovoltaic include its emission free generation, non-depleting resource and cost effective as compared to conventional energy resources. Among various types of solar cells, silicon solar cells have attained the highest solar cell power conversion efficiency of around 28% [1]. However, due to its difficult manufacturing and high material cost of silicon solar cell, other methods of energy generation using solar photovoltaic are gaining more attention [2-4]. Dye sensitized solar cell are gaining enormous attention due to its less manufacturing cost, easy to synthesize and better efficiency outcomes [5-8]. However, research has been carried out to increase to dye sensitized solar cell efficiency by studying various other materials for its fabrication [9-10].

Dye sensitized solar cell consist of a photo-anode, dye sensitizer, electrolyte and counter electrode as shown in fig. 1. The dye sensitized generates an electron hole pair which is transfer to the photo-anode [11-12]. The shifting of electron from the dye to the photo-anode is carried out owning to the lower band-gap of photo-anode as compared to the dye. This results in the shift of generated electron from the conduction band of the dye to the conduction band of the photo-anode [13].

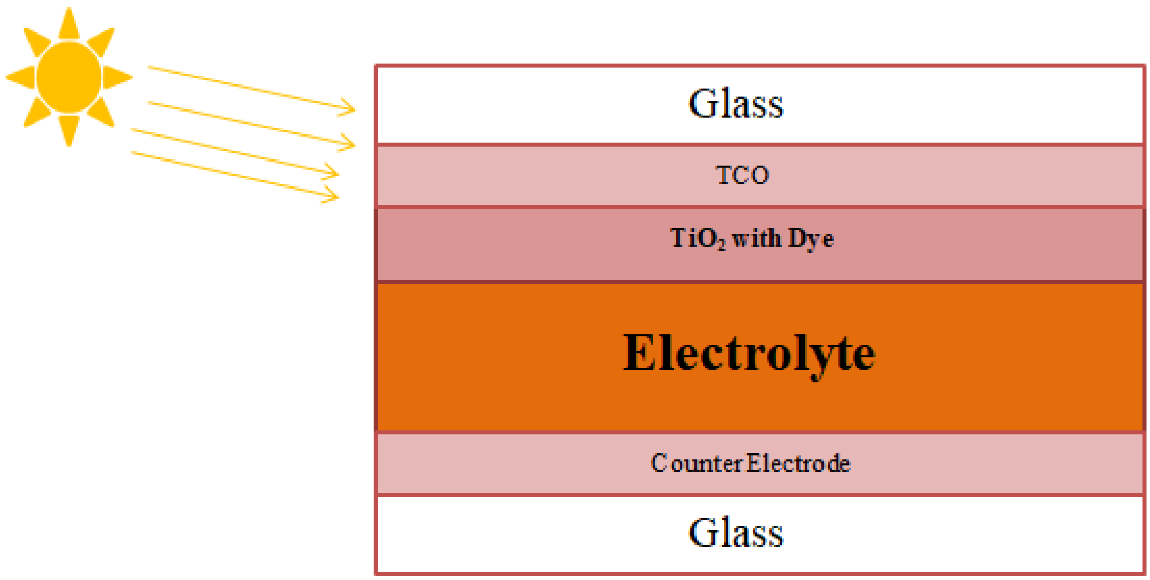


Fig. 1: Components of a typical dye sensitized solar cell

The photo-anode moves the electron to the external circuit [14-15]. The electron entered the circuit again via the counter electrode and a redox reaction takes place at the electrolyte present next to the dye to neutralize the hole with an electron [16]. All the components used in this type of solar cell plays important role in the generation of electricity. However, dye plays a fundamental role in the generation of electron-hole pair when sunlight falls on it. The function of a photo-sensitizer (Dye) is to absorb light, generate an electron-hole pair and transfer that electron to the conduction band of the semi-conductor anode next to it. Dye sensitizer based on transition metals has given the best efficiency till now. There are multiple metal-based dyes, metal free dyes and natural dyes that are being used in DSSC [17-20]. The dye should have a band-gap higher than the photo-anode, capability to show absorption in visible region, Load/absorb properly on to the semi-conductor surface, must possess the ability to remain stable in its oxidized form, the HOMO of the Dye must be more positive then the redox potential of the electrolyte [21-23].

In case of metal complex sensitizer, the ligand plays the role of defining the properties of the dye. Properties like adhesion with the semiconductor, charge transfer properties are defined by the ligand. Considering the properties required for a dye, Ruthenium (II) poly-pyridyl provides with the best power conversion efficiency [24-26]. This Ruthenium based dye i.e N-719 gives photo-stability, excitation properties like good life time and more-over easy redox reaction from electrolyte [27-30]. This dye consists of two photons which gives better absorption of light and electron transfer to the semi-conductor [31-33]. However, the dye process parameters play a fundamental role in defining the efficiency of the solar cell. These parameters include type of dye used, dye concentration and time of dipping of photo-anode in dye. Various research works has been carried out by using various metal oxide, metal complex, natural and metal free dyes but Ruthenium (II) poly-pyridyl has reportedly gives the best output power conversion efficiency. However, changing the parameters of Ruthenium (II) poly-pyridyl including its solution concentration and dipping of photo-anode in the solution would result in a variation of the efficiency of the solar cell. For parametric estimations, various simulation tools are used including MATLAB Fuzzy logic tool, ANSYS, TRANSYS. However, fuzzy rule based system provide a more appropriate solution in comparison to other techniques owing to its more real time data analysis and close to human thinking. In this work, a parametric estimation has been carried out for Ruthenium (II) poly-pyridyl dye parameters with TiO2 nano-particles photo-anode, $I3^{-}/I^{-}$ electrolyte and platinum electrode. MATLAB fuzzy logic controller is used to analyzed the effect of Ruthenium (II) polypyridyl concentration in dye solution and time for which the photo-anode is dipped in the dye and its effect on output solar cell power conversion efficiency.

**Fuzzy Analysis**

There are different simulation tools that can be adopted to check the experimentalist parametric estimation and efficiency of the design before it is built up. These simulation tools include MATLAB, ANYSY, and TRANSYS for parametric, mechanical, structural, magnetic, piezo-electric, pyro-electric estimations of any device. Among these techniques, FLC (Fuzzy Logic Controller) is a highly efficient technique that provides very valuable flexibility for reasoning. This is a good way to consider the inaccuracies and uncertainties of any experiment. It is a technique to impose human-like thinking into a controlled experiment.

MATLAB Fuzzy analysis is used to study the effect of Ruthenium (II) poly-pyridyl concentration in dye solution and time for which the photo-anode is dipped in the dye and its effect on output solar cell power conversion efficiency. Fig. 2 shows the FIS figure having two inputs concentration of dye in ethanol solution and dipping time of anode in the dye and its effect is studied on the output power conversion efficiency.

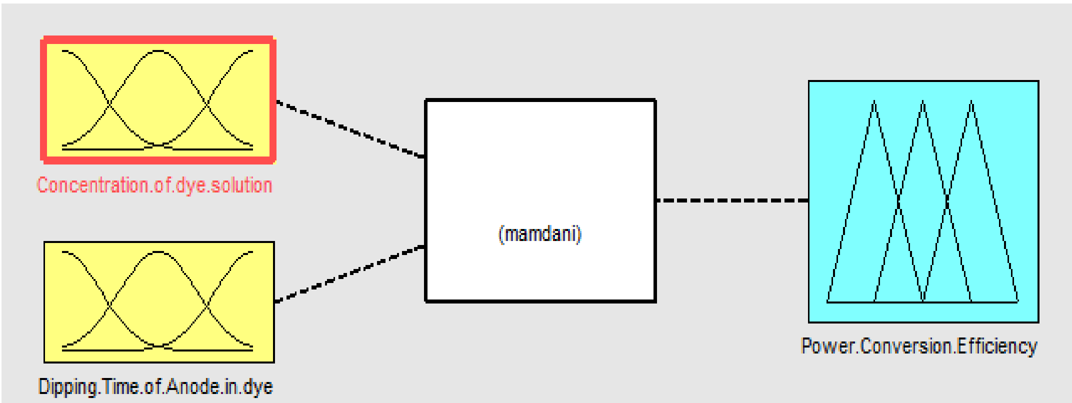


Fig. 2: FIS diagram for the parametric estimation of dye.

Membership functions and ranges for the input as well as output is added in the membership function editor. The range for the input concentration of dye solution is taken from 1-10% of Ruthenium (II) poly-pyridyl in ethanol solution. Similarly the time of dipping of anode in dye is taken from 2 hours to 24 hours. The output power conversion efficiency is taken in range of 3 to 8%. The membership function for the input are taken as low, medium and high and from output the membership functions are taken as small, middle and large. The membership function for the input dye concentration and time of dipping of anode is dye are shown in fig. 3 and 4 and the membership function for output power conversion efficiency is shown in fig. 5.

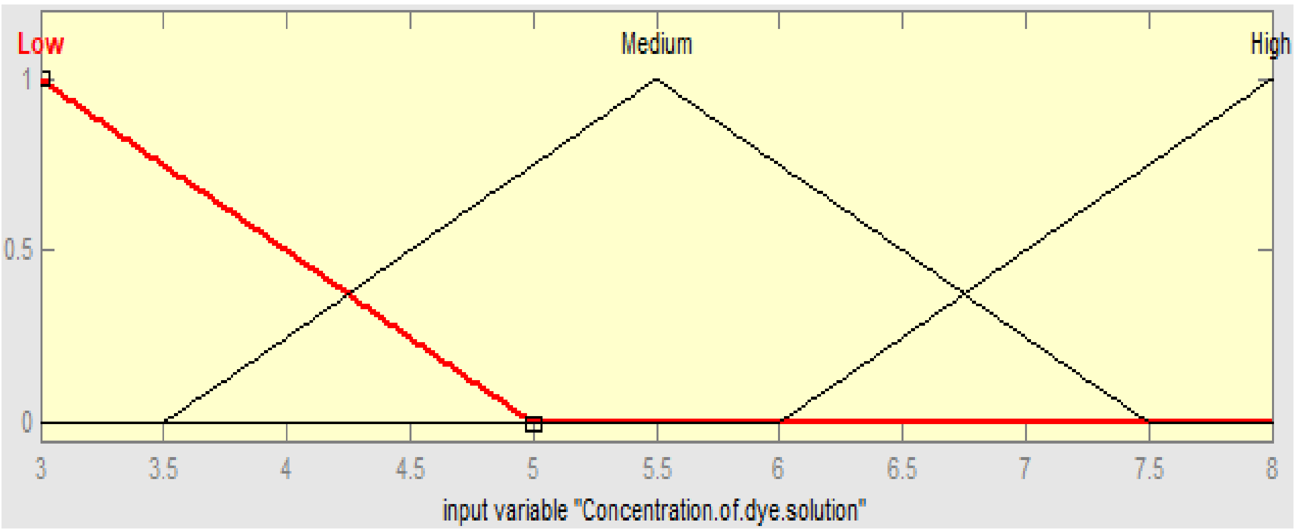


Fig. 3: Membership function of input Concentration of dye solution

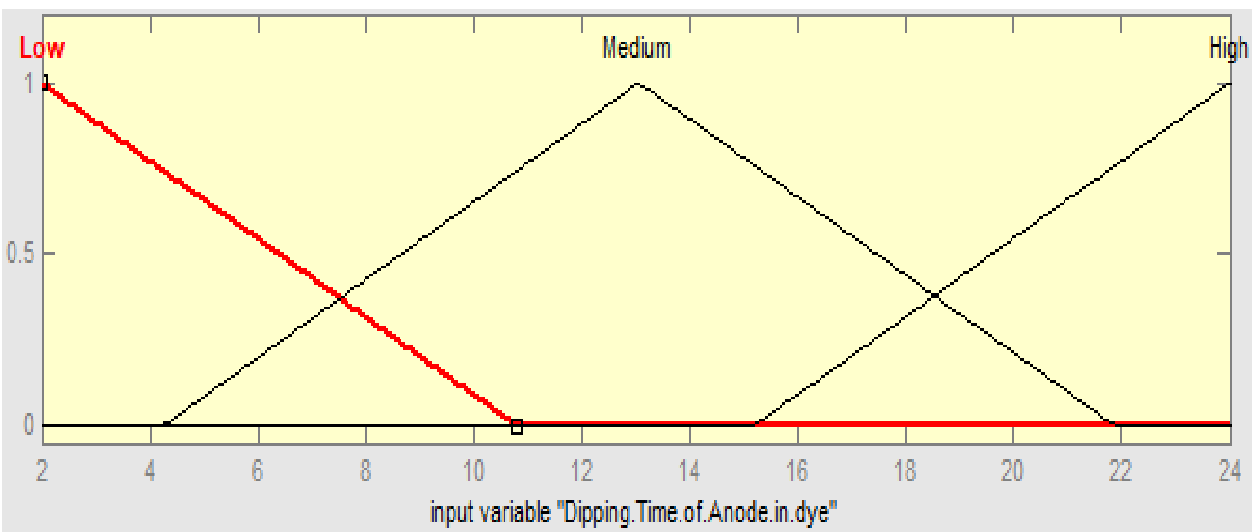


Fig.4: Membership function of input Dipping time of anode in dye

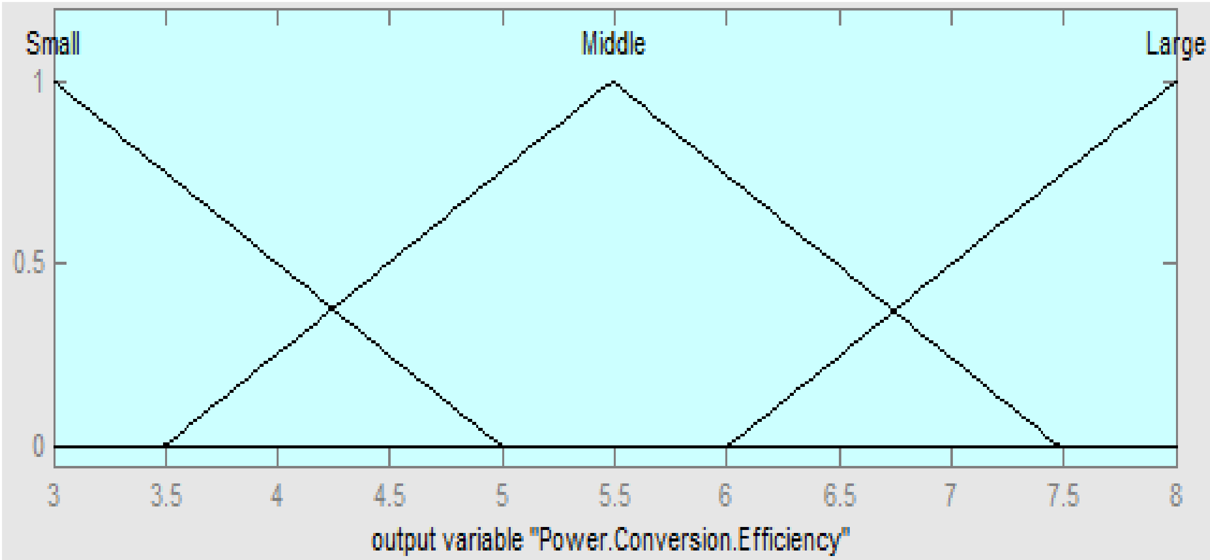


Fig. 5: Membership function for output power conversion efficiency

The membership function and ranges of input and output are shown in table 1.

Table 1: Membership functions and ranges of input and output

| Input/output | Membership function | Ranges |
|---|---|---|
| **Concentration of dye solution** | Low | 3-5 % |
| | Medium | 3.5-7.5% |
| | High | 6-8% |
| **Joystick 2** | Low | 2-11 hours |
| | Medium | 4-22 hours |
| | High | 15-24 hours |
| **Power Conversion Efficiency** | Small | 3-5% |
| | Middle | 3.5-7.5% |
| | Large | 6-8% |

On the basis of the membership functions and inputs, the number of rules is defined. The rules are defined based on the real time data. The number of rules defined in this simulated is equal to $3^N$ where n is the number of inputs. The total rules defined are equal to 9 as shown in Table 2. The rules are entirely based on the data generated from human thinking and expert with real time analysis. On the basis of the defined rules, the 3D and 2D graphs are studied.

Table 2: Defined Rules for input and output

| Concentration of dye solution | Dipping Time of Anode in Dye | Power Conversion Efficiency |
|---|---|---|
| Low | Low | Small |
| Low | Medium | Middle |
| Low | High | Small |
| Medium | Low | Large |
| Medium | Medium | Middle |
| Medium | High | Small |
| Large | Low | Middle |
| Large | Medium | Middle |
| Large | High | Middle |

**Results and Discussion**

Fig. 6 shows the 2D graphs between input concentrations of dye solution with the output power conversion efficiency. More the concentration of dye solution better will be the absorption of the molecules on the photo-anode which will lead to an increase in the solar cell efficiency. Fig. 7 shows the 2D graphs between input dipping times of photo-anode in dye solution with the output power conversion efficiency. No major effect on the efficiency is seen till the time of 15 hours, however, after 15 hours, the output efficiency gradually decreases. This shows that photo-anode degradation happens. As the dye solution contains ethanol, the ethanol affects the surface of photo-anode which results in degradation [29]. This indicates that recombination effects start to reverse the increasing trend as a result of more dye molecules, which causes quenching of the photo-excited electrons and leads to a reduction of charge injection.

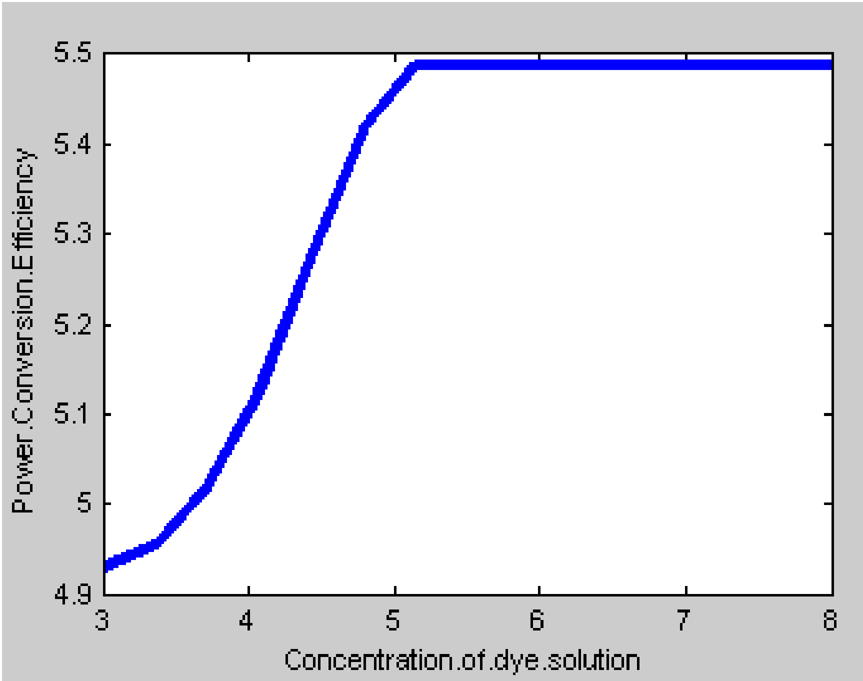


Fig. 6: 2D graphs of output power conversion efficiency with respect to (a)Concentration of dye solution

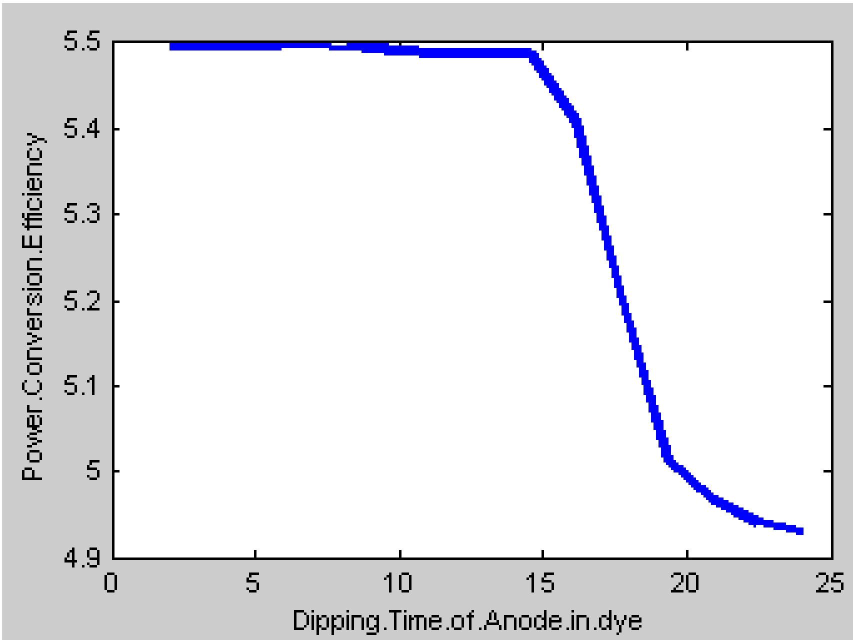


Fig. 7: 2D graphs of output power conversion efficiency with respect to Dipping time of anode in dye

Fig. 8 shows the 3D graph between the input concentration of dye solution and dipping time of the photo-anode with respect to the output power conversion efficiency.

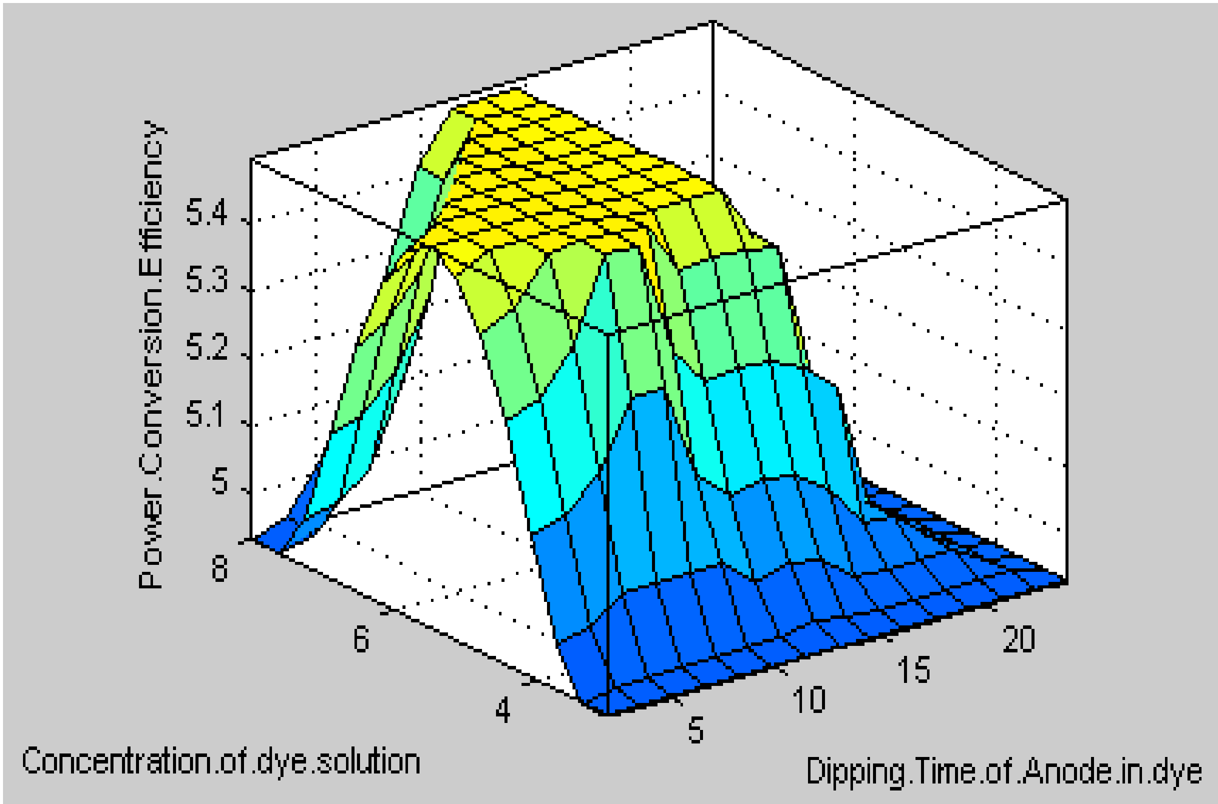


Fig. 8: 3D graph between the input concentration of dye solution and dipping time of the photo-anode with respect to the output power conversion efficiency.

The dye solution and dipping time of dye thus have significant effect on the output power conversion efficiency. The results are in accordance with the literature [29]. The simulated values and MAMDANI model calculated values are compared using the values of input as well as output from the rule viewer as shown in fig. 9.

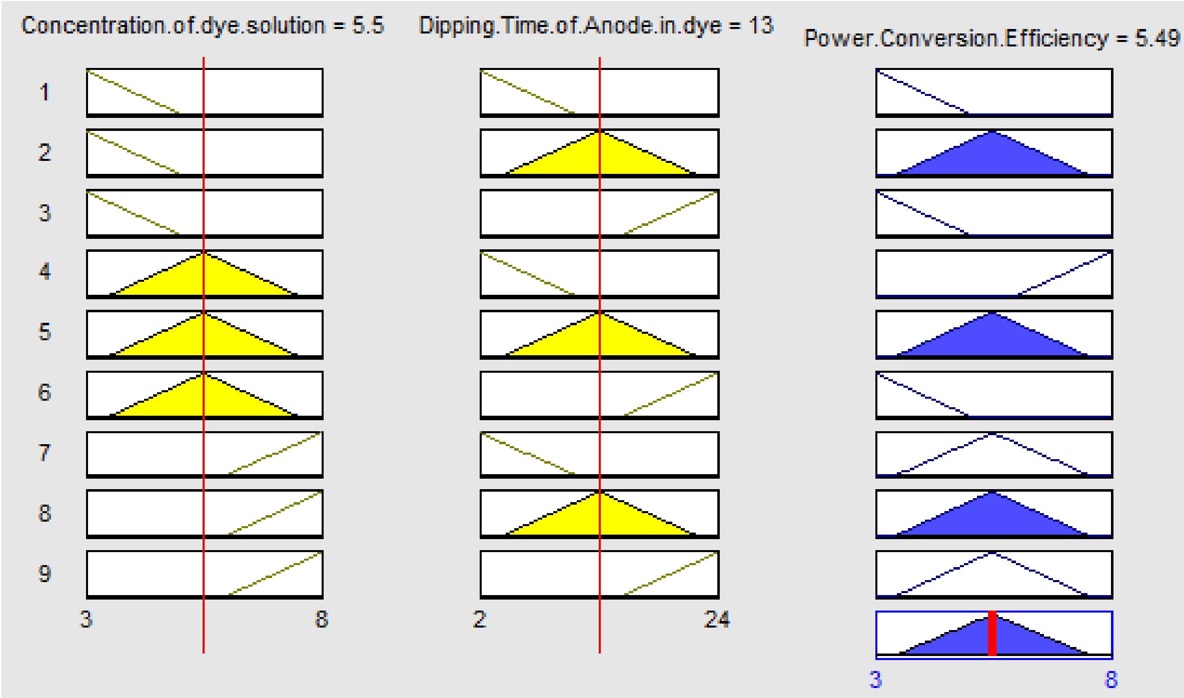


Fig. 9: Rule viewer for the simulated value.

For the input crisp value of 5.5% of concentration of dye solution and 13 hours of dipping time of anode in dye, 4 membership function values are calculated as shown in the below.

$$Z_1 = 8\text{-}5.5/8 = 0.3125\%$$

$$Z_2 = 1\text{-}Z1 = 0.6875\%$$

$$Z_3 = 24\text{-}13/24 = 0.45 \text{ hrs}$$

$$Z_4 = 1\text{-}Z3 = 0.55 \text{ hrs}$$

Based on these four values and 4 rules out of the 9 rules, the output sum of membership functions and singleton values is calculated which is used to calculate the output power conversion efficiency value based on MAMDANI model value as shown below,

$$\text{Mamdani's Model} = [\Sigma\ (Mi \times Si)\ /\ \Sigma Mi]\ {*}100$$

Simulated value of Power Conversion Efficiency = 5.49%

MAMDANI model calculated value of Power Conversion Efficiency = 5.51%

Table 3 shows a comparative analysis between the calculated value and MAMDANI simulated value as per rule viewer.

**Table 3.** Comparison of simulated and calculated values

| | Simulated Value | Calculated Value | Error |
|---|---|---|---|
| Output Power Conversion Efficiency | 5.49% | 5.51% | 0.02 |

The parameters of dye thus largely affect the dye sensitized solar cell power conversion efficiency.

## Conclusion

Effect of dye concentration and dipping time of anode in dye is analyzed for a dye sensitized solar cell using MATLAB fuzzy logic controller. The output shows an increment in the solar cell efficiency with an increase in the concentration of Ruthenium dye in the ethanol solution. More the molecules of dye are absorbed on the surface of the photo-anode, better would be its light absorption capabilities. Similarly, with increase in the time of dipping of photo-anode in dye solution results in decrease in efficiency which is mainly attributed to the degradation of photo-anode in dye solution. The simulated and MAMDANI calculated values are compared which shows an error of 0.02% which shows the accuracy of this work.

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