

REMOVAL OF THE DUST PARTICLES FROM SOLAR PANELS FOR IMPROVEMENT OF EFFICIENCY USING FUZZY LOGIC

Imran Javed Khan^{1,*}, Maham Akhlaq^{1,**}, Faheem Qasim¹

¹ Department of Electronics, GC University Lahore

*Corresponding author: imrankhan@gcu.edu.pk

**Corresponding author: maham_9458@hotmail.com

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*Corresponding Author:

Imran Javed Khan, Maham Akhlaq:
imrankhan@gcu.edu.pk,
maham_9458@hotmail.com

ABSTRACT

An effective and sustainable solar energy generating system is needed given the current global energy problem. The need to use solar energy properly is necessary because it is one of the most readily available sources of energy. The conversion of solar energy to electric energy uses silicon solar panels, which have an efficiency of between 15% and 20%. The solar cell efficiency is nevertheless decreased by the dust that wind and storms bring. In this study, a sensor-based system is used to monitor the dust buildup on the solar panel and to remove the dust by washing and moistening the panel's surface. The output conversion efficiency and sensor data are taken into consideration by a fuzzy logic system, which forecasts when the solar panel will need to be cleaned.

Keywords: Solar panel, Fuzzy logic, Sensor, Power conversion efficiency



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Original Research Article

Introduction:

The rise in world energy demands require certain clean and sustainable energy resources. Conventionally used energy resource are widely being used as a mean to generate energy [1, 2]. These resources including energy generated by combustion of fossil fuels present inside the earth crust including coal, natural gas and oil [3]. However, since these fuels takes millions of years and a lot of pressure to be converted to useful fuel these resources are considered depleting based on their current usage. Similarly, burning these fuels to convert them to electrical energy results in generation of green-house gases including carbon dioxide and carbon monoxide [4, 5]. These gases

are one of the main contributors in the rise in the global temperature and pollution. To minimize the use of conventional energy resource owing to their large number of drawbacks, new and advance technology including renewable energy technology are considered. Renewable energy generation uses sustainable energy resources including solar energy, wind energy, water and biomass in order to generate energy including fuels and electricity [6-9].

As solar energy is readily available across the global during the day. As per NASA, the daily average of solar irradiation that reaches the earth surface is 5.0 kWh/m^2 . The solar energy is converted to the electricity using photovoltaic effect[10]. The system that is used in order to generate electricity from solar light is solar panel. Solar panel are basic p-n junction silicon semiconductor materials, which generate an electron hole pair when a photon of light larger than the band-gap of the silicon atom strikes the surface of the solar panel [11-13]. The output voltage and current depends on the fill factor and power output. The output power conversion efficiency in a solar panel depends on the power input and power output. Power input is the amount of power absorbed by the solar panel and the power output is the voltage and current generated by the solar panel.

There are several factors which are considered as the main contributors to solar cell efficiency. The efficiency depends on the amount of photon of light absorbed and number of electron hole pairs generated as a result of the photon of light [14, 15]. Larger the number of electron hole pair generated, larger will be the voltage and current as well as the power conversion efficiency. However, there are several external factors which significantly contribute in decreasing the power conversion efficiency of the solar panel. These factors includes roof orientation, solar shading, climate (snow or heat), Low and high temperature, poor maintenance and dust [16-20]. According to the US Department of Energy, airborne dust particles can lower efficiency by up to 7%, which equates to \$10,000 in lifetime value loss for residential solar systems and is substantially greater for large-scale solar farms. In some regions of the world, air pollutants build up, lowering the energy output of solar panels by more than 25%. Dust can be in the form of particulates of dirt and air molecules. According to chemical study, 92% of dirt is dust. Despite making up a lesser portion of the overall detritus in the solar panels, these dust pollutants can nonetheless cause a significant energy loss. Alghamdi et.al, designed a fuzzy control system which automatically clean the solar panel however, it results in waste of water [21]. The fuzzy system provide a parametric estimation based on real life and literature. It acts like a decision tool which depicts the outcomes of the parameters which depends on the input [22-24]. This work provides a simulated control system which has the ability to predict the required of solar panel cleaning only when the solar panel efficiency decreases to a certain level. This system can help in reducing the water losses during the day while cleaning the solar panel.

Methodology:

MATLAB fuzzy rule-based system is used in order to predict the requirement of dust cleaning. The system predicts the requirement of the DC motor operating cleaning system which depends on the output current, voltage and well as the power conversion efficiency. The power conversion efficiency is categorized as the ratio of energy produced to the total solar energy that is absorbed by the solar panel. The output voltage, current as well as the power conversion efficiency depends on the amount of electricity that the solar panel can generate which highly depends on the amount of solar light which can be absorbed by the system. Dust on the solar panel is expected to reduce

the power conversion efficiency. DC motor to sprinkle water and clean the solar panel. Dust sensor is used to monitor the dust accumulated on the panel, voltage sensor to predict the output voltage and current sensor to predict the output current.

The proposed system control system in order to continuously monitor the system and create as well as generate a decision based on the change is output for cleaning the solar panel is shown in figure 1.

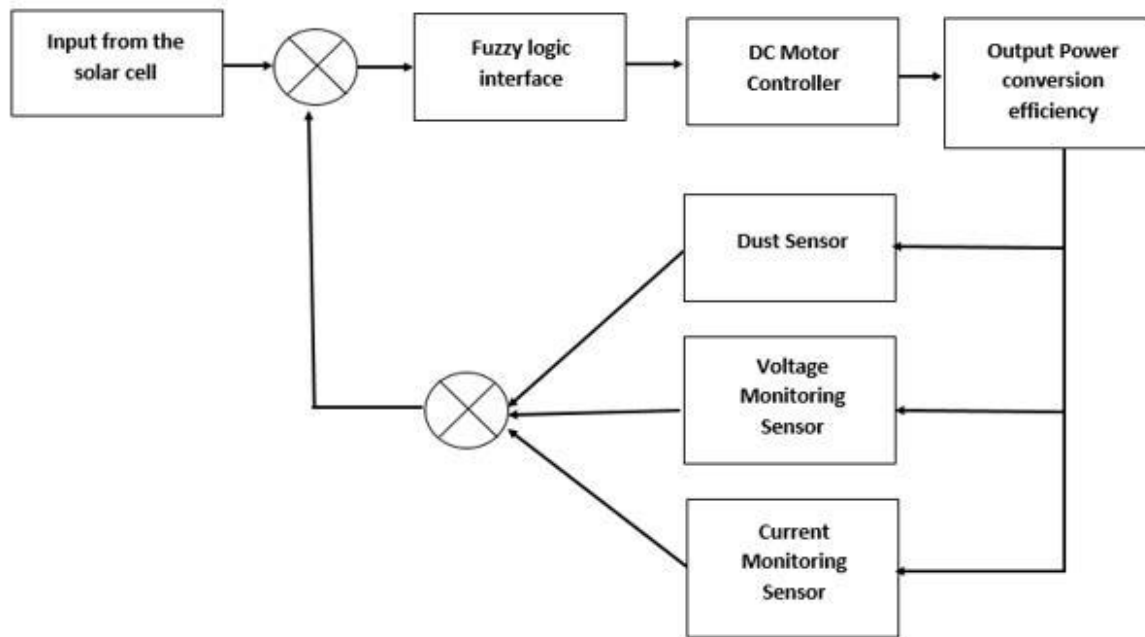


Fig. 1: Block diagram of the proposed control system

The dust sensor data, voltage monitoring sensor data and current monitoring sensor data are taken as input and the requirement of action is taken as output which changes based on the input parameters. The input and output for the work are added to the FIS of the fuzzy system in MATLAB using MAMDANI model, which is shown in figure 2.

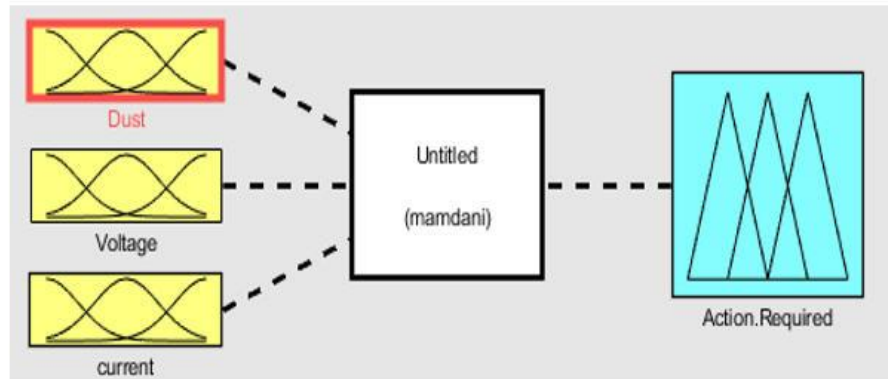


Fig. 2: FIS of the dust monitoring control system

The ranges and membership functions are then added using the membership function editor. The input membership functions and range for the input are shown in figure 3. The range for dust data from the sensor is taken from 0.1 to 0.5 with membership functions of small, medium and large. The range for voltage is taken from 23-37 V with membership functions of small, medium and large. The range for current is taken from 3 to 9 mA with membership functions of small, medium and large.

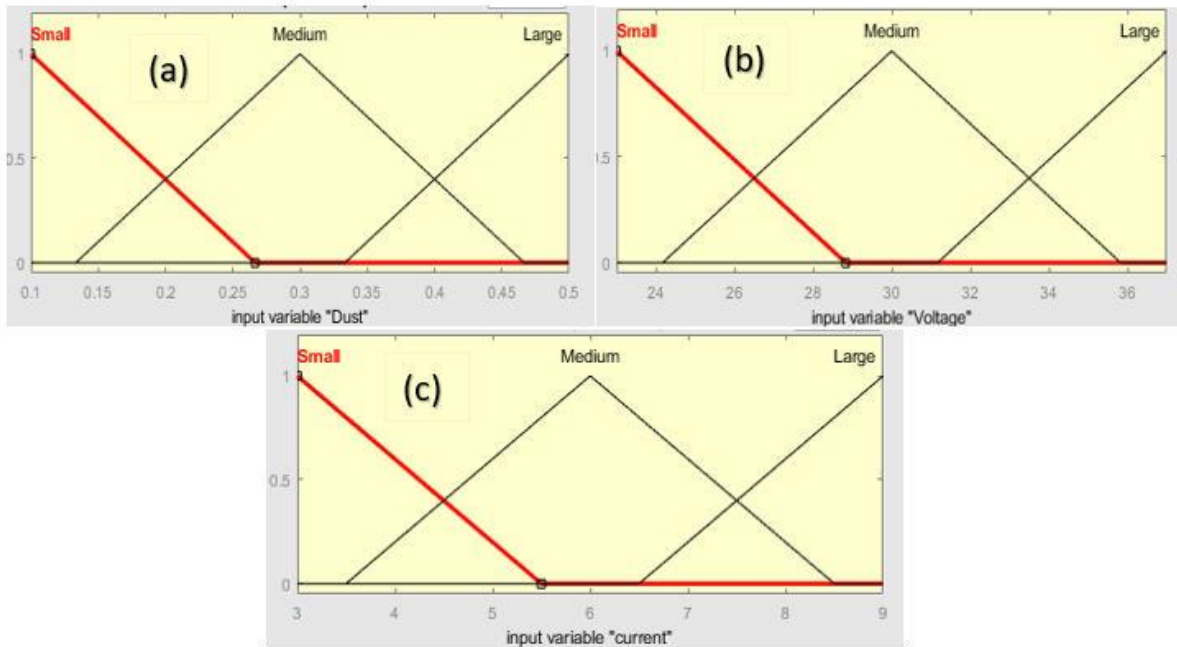


Fig. 3: Membership functions for input (a) Dust (b) Voltage (c) Current

The range of output action required is taken from 0-1 with membership function small, medium and large as shown in figure 4.

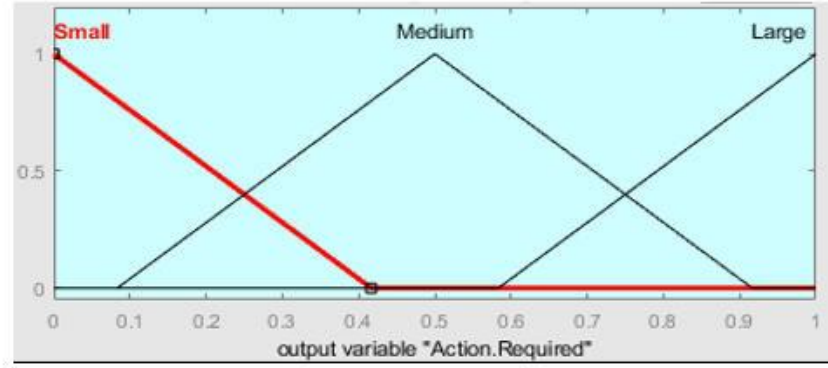


Fig. 4: Membership functions for output “Action Required”

After finalizing the input and output membership functions, the rules are finalized. The number of rules are defined by the number of membership functions and number of rules. The number of rules are equal to m^n where m is the number of membership functions and n is the number of rules. For this work, the number of rules are 27. The rules are defined based on the real life scenarios and literature. The selected rules are shown in table 1.

Table 1: Selected rules for the control system to dust monitoring

Rule No.	Dust	Voltage	Current	Action Required
1	Small	Small	Small	Small
2	Small	Small	Medium	Small
3	Small	Small	Large	Small
4	Small	Medium	Small	Small
5	Small	Medium	Medium	Small
6	Small	Medium	Large	Small
7	Small	Large	Small	Small
8	Small	Large	Medium	Small
9	Small	Large	Large	Small
10	Medium	Small	Small	Small
11	Medium	Small	Medium	Medium
12	Medium	Small	Large	Medium
13	Medium	Medium	Small	Medium
14	Medium	Medium	Medium	Medium
15	Medium	Medium	Large	Medium
16	Medium	Large	Small	Medium
17	Medium	Large	Medium	Medium
18	Medium	Large	Large	Small
19	Large	Small	Small	Large
20	Large	Small	Medium	Large
21	Large	Small	Large	Medium
22	Large	Medium	Small	Medium
23	Large	Medium	Medium	Medium
24	Large	Medium	Large	Medium

25	Large	Large	Small	Large
26	Large	Large	Medium	Medium
27	Large	Large	Large	Large

The MATLAB fuzzy system provide the 2D and 3D graph along with the rule viewer in order to shows the impact of input on output.

Results and Discussion

The 2D graph between input and output are shown in figure 5. The impact of current on action required is shown in figure 5 (a). With low current conditions, action is required in terms of removing dust. Low current conditions also represent other factors effecting the solar cell efficiencies. The impact of voltage on action required is shown in figure 5 (b). With low voltage conditions, action is required in terms of removing dust. Low voltage conditions also represent other factors effecting the solar cell efficiencies. The impact of dust accumulated on the solar panel and action required is shown in figure 5 (c). Low dust conditions required minimal to low action requirement. With increase in dust accumulated on the solar panel measured using dust sensor, the requirement of the action increases.

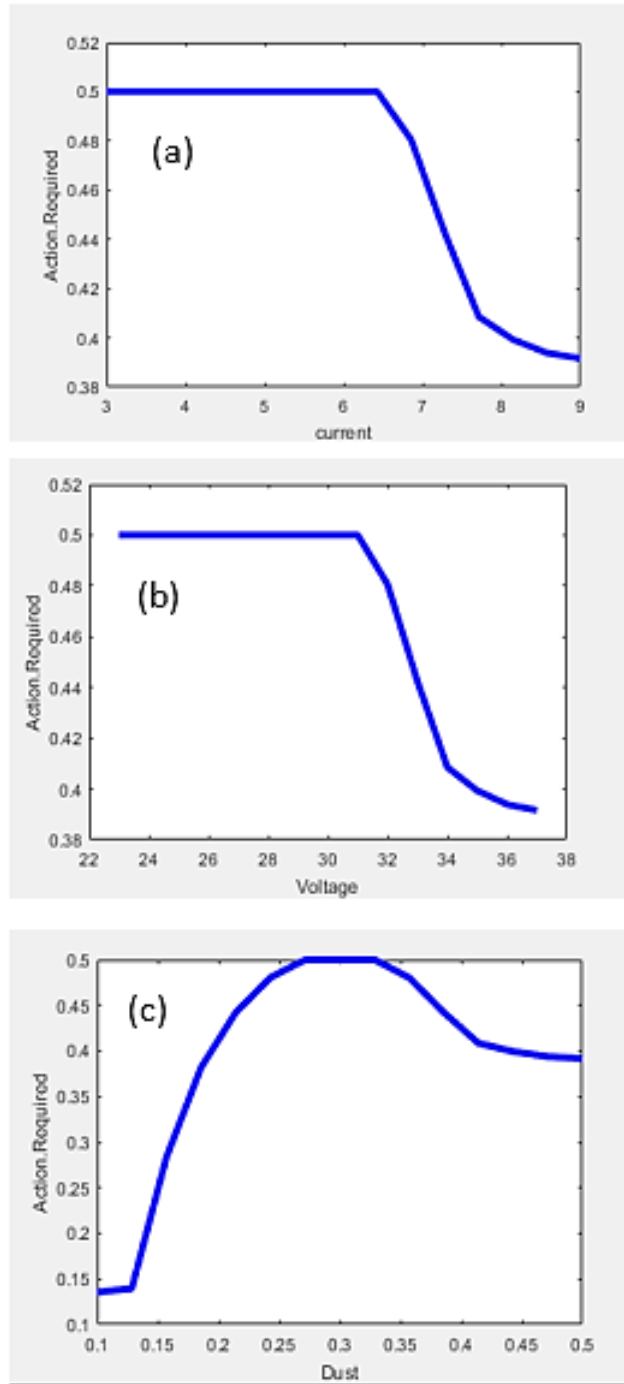


Fig. 5: 2D graph between output actions required with input (a) Current (b) Voltage (c) Dust

3D graph between input voltage and dust with output action required is shown in figure 6 (a). The graph is in accordance with the 2D graph. The decrease in voltage and increase in dust accumulated on the solar panel require action. 3D graph between input current and dust with output action required is shown in figure 6 (b). The graph clearly shows that when the current is low and dust is

high, the action required in maximum and the DC motor must operate in order to clear the solar panel from dust accumulated on it.

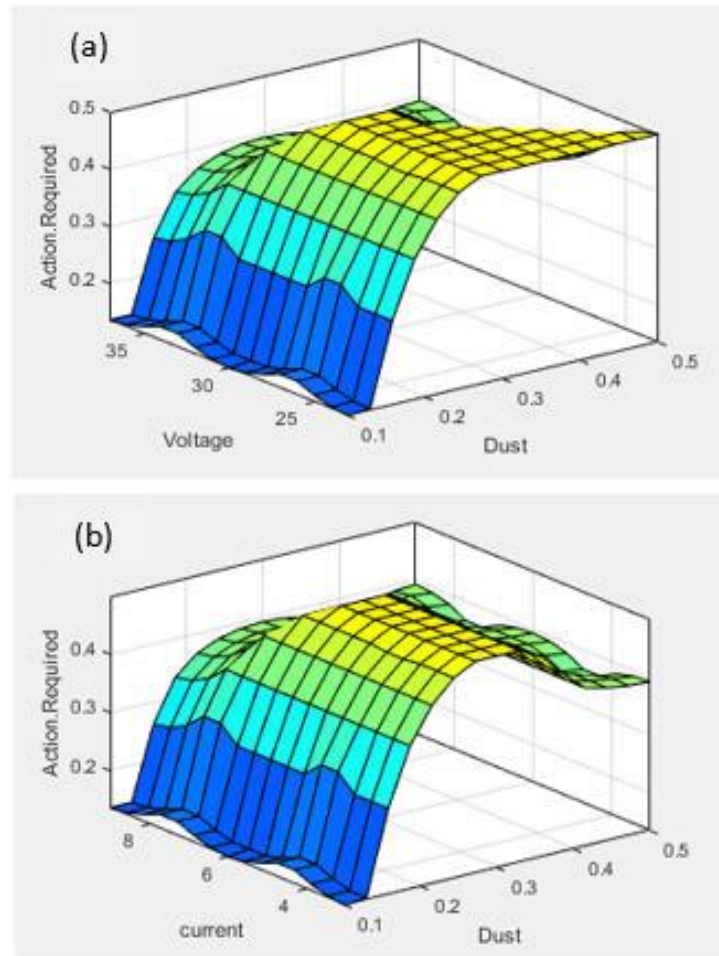


Fig. 6: 3D for output action required with input (a) Voltage and dust (b) Current and dust

The simulated values from the rules defined and 2D and 3D model is shown in figure 7. The rule viewer shown in figure 7 shows the crisp value of output for a specific value of input. The input values are then used for the calculation using the MAMDANI model formula. The minimum membership function values are calculated using the equation as shown below,

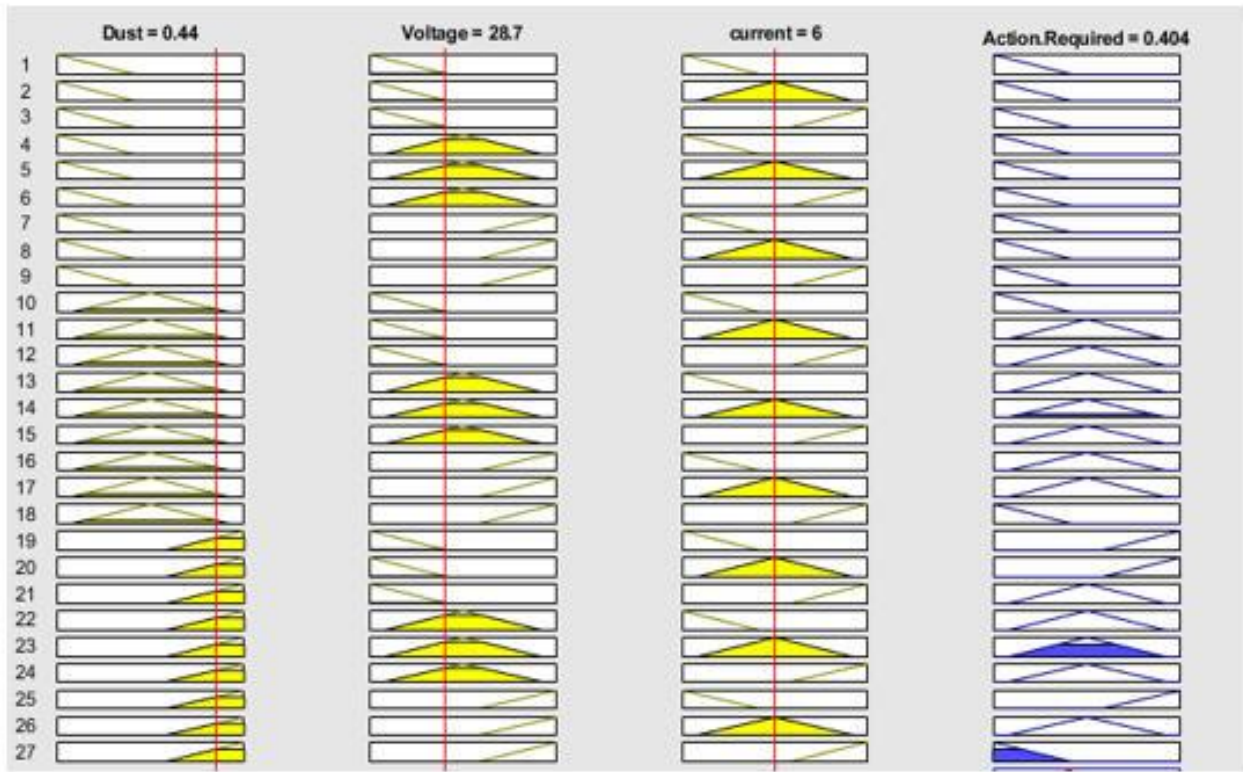


Fig. 7: Rule viewer for the control system design

Minimum membership function for input 1 Dust are shown in equation 1 and 2

$$K1 = 0.5 - 0.44/0.5 = 0.12 \quad (1)$$

$$K2 = 1 - K1 = 0.88 \quad (2)$$

Minimum membership function for input 2 Voltage are shown in equation 3 and 4

$$K3 = 37 - 28.7/37 = 0.224 \text{ V} \quad (3)$$

$$K4 = 1 - K3 = 0.776 \text{ V} \quad (4)$$

Minimum membership function for input 3 current are shown in equation 5 and 6

$$K5 = 9 - 6/9 = 0.33 \text{ mA} \quad (5)$$

$$K6 = 1 - K5 = 0.67 \text{ mA} \quad (6)$$

The calculation for the analysis of the output crisp value based on the minimum membership function and the singleton value is shown in table 2 using the MAMDANI model formula shown in equation 7.

Where,
$$P = [\sum (R_i \times S_i) / \sum R_i] \quad (7)$$

R_i = values of the selected rules

S_i = the singleton value (0 to 1)

Table 2: Output calculations for the MAMDANI model formula

Dust	Voltage	Current	Action Required	Minimum Membership function value (R_i)		Singelton Value (S_i)	$R_i \times S_i$
Medium	Medium	Small	Medium	$K1 \wedge K3 \wedge K5$	0.12	0.003	0.00036
Large	Small	Small	Large	$K1 \wedge K3 \wedge K6$	0.12	0.005	0.0006
Large	Small	Medium	Large	$K1 \wedge K4 \wedge K5$	0.12	0.005	0.0006
Small	Small	Large	Small	$K1 \wedge K4 \wedge K6$	0.12	0.001	0.00012
Medium	Medium	Large	Medium	$K2 \wedge K3 \wedge K5$	0.224	0.003	0.000672
Medium	Large	Small	Medium	$K2 \wedge K3 \wedge K6$	0.224	0.003	0.000672
Large	Large	Large	Large	$K2 \wedge K4 \wedge K5$	0.22	0.005	0.0011
Large	Large	Small	Large	$K2 \wedge K4 \wedge K6$	0.67	0.005	0.00335
$\sum R_i$					1.818	$\sum R_i \times S_i$	0.007474

$$\text{MAMDANI Model formula calculated value} = \frac{\sum R_i \times S_i}{\sum R_i} \times 100$$

$$\text{MAMDANI model Formula calcuated value} = (0.007474/1.818) \times 100$$

$$\text{MAMDANI model Formula calcuated value} = 0.004111 \times 100$$

$$\text{MAMDANI model Formula calcuated value} = 0.4111$$

$$\text{Simulated value} = 0.404$$

$$\text{Difference} = 0.00711$$

$$\text{Error} = 0.7\%$$

The difference between the simulated and calcuated value is less than 1% which shows the accuracy of the work.

Conclusion

The dust accumulated on the solar panel results in decrease in its output voltage and current as well as efficiency. This required cleaning action for dust removal. The proposed system using dust sensor data, output current and voltage data to predict the cleaning action is reported in this work using MATLAB fuzzy rule based system. Fuzzy rule based system predict that the action is minimum which the voltage and current is high. Similarly, the Fuzzy rule based system predict

that the action is maximum which the dust accumulated on the panel is high. The different between the simulated and calculated value is less than 1% which shows the accuracy of the work

Author's Contribution: M.J.K., Conceived the idea; M.J.K., M.A Designed the simulated work and F.Q., did the acquisition of data; M.J.K., M.A., Executed simulated work, data analysis or analysis and interpretation of data and wrote the basic draft; M.A., F.Q., Did the language and grammatical edits or Critical revision.

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