Design of a Fuzzy Logic Controller for an Energy Efficient Small Scale Integrated Solar Photovoltaic-Solar Water Distillation System

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Abstract:

A fuzzy- logic controller to provide dynamic control over the various components of an energy efficient small scale integrated solar photovoltaic-solar water distillation system is designed. The system will cater to the requirements of an isolated residential building that is connected to utility electric supply mains as well as municipal water supply but both of the supply systems are often inadequate and erratic. The proposed system aims at substantial improvement in the overall efficiency of energy utilization. The efficiency of the photovoltaic module strongly depends on its temperature, hence a cooling arrangement with a heat exchanger is included. The waste heat recovered by the exchanger will be utilized by the water distillation process, that will receive solar radiation directly also. The electrical energy generated by the photovoltaic module will be consumed directly by some dc operated essential devices such as a small refrigerator, lights and fans, avoiding losses in inversion from dc to ac. The surplus energy will be stored in the battery, and while the battery is fully charged up, it will be utilized in the water distillation sub-system. The controller has been successfully validated under the weather conditions in the month of June in Delhi and the performance of the proposed system is predicted by simulation.

Keywords: Fuzzy Logic Controller, Integrated Energy System, Waste Heat Recovery

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1. Introduction

In many remote suburban locations, people face problems of frequent power cuts and perennial shortage of safe drinking water [1 - 4]. Whereas breakdowns of electricity lead to acute discomfort and disruption of normal life, lack of adequate and safe drinking water is the root cause of many health- related problems. In summers these difficulties are much more pronounced. On the one hand the demand for electrical energy sharply increases in summers and on the other hand it suffers from inefficient utilization and wastages. All over the world distributed generation with hybrid systems using renewable sources is a well recognized and thoroughly studied subject [5-16], though economics of the centralized generation, transmission and distribution almost always warrantee acceptance of the later. The prohibitive costs of solar photovoltaic and small scale renewable energy systems (such as aero generators) coupled with their intermittence and unreliability are usually the deciding factors going against them. A viable solution is to utilize the renewable energy source, partly depending on the grid supply, under a suitable control system that will ensure efficient utilization of the available energy while giving due consideration to the preferential loads.

The necessity to treat the drinking water with the solar UV and thermal energy has also attracted considerable research work [2-4]. It has a potential to utilize the available solar radiation incident on a given surface area to its optimum level. In the present study, the 'waste heat' extracted from the solar photovoltaic module (SPV), is proposed to be utilized in the distillation process, and also the surplus electrical energy generated by the SPV, while it is not being consumed by the isolated load of house hold and the battery stands fully charged up, will be utilized in the distillation process.

The performance of such an integrated energy system necessitates an effective dynamic control system. During the last couple of decades, the control systems based on Fuzzy Logic have been extensively studied [18-23]. The present paper presents the design and development of a Fuzzy Logic controller (FLC) based on Matlab tool 'FIS Editor'. Its performance has been successfully validated for the diurnal weather data for the month of June in Delhi. The outputs of the FLC will be used to control the various components of the system through a personal computer.

The intensity of solar radiation incident on a given surface varies with time, weather conditions and the sky clear ness index (CI). In the present study weather data for the month of June in Delhi, has been taken from Mani's Handbook [17]. It provides hourly values of solar radiation (Is) on a horizontal surface, under clear sky (CI=1). When the sky is overcast with clouds and dust etc., the available solar energy will be (CI) x Is per unit area of the horizontal surface.

In a typical renewable power generation system, a storage battery has a very important role. For its proper functioning, the state of charge of the battery has to be carefully maintained and the conditions of deep discharge or over-charge must be avoided. Several models have been presented by researchers such as [24-27] which can be used to analyze the performance of a storage battery. We use a simplified model in which the battery is a storage element with a reference value of state of charge (SOC) assigned as zero. When the battery is fully charged up, its SOC is 1. It is assumed that the operation of the battery will be controlled in such a way that its SOC will remain within the normalized values, 0 to 1.

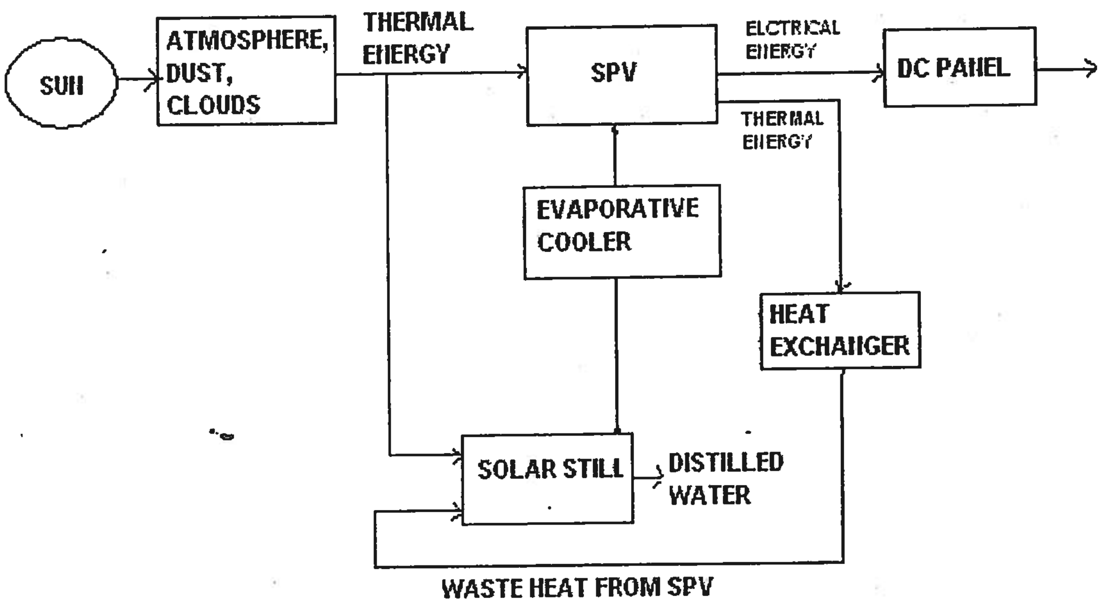

Fig.1a: A schematic diagram showing the Photovoltaic module with a heat exchanger, evaporative cooler and a solar still.

The electrical energy converted by the SPV will be fed into the controlled system. The priority dc loads viz. one refrigerator, two lights and two fans will be connected to the dc panel. These loads will consume energy from the storage battery while the SPV does not generate. During the generation period of the SPV, a portion of the generated electrical energy will be available for charging up the battery, another portion to run the dc loads and the surplus energy will be utilized by the heaters in the solar still, as shown in Fig. 1b.

The dc Loads

The full load power of the proposed refrigerator, two lights and two fans will be 240W. When only a fraction (X) of the load is on, its consumption will be X times 240 W. These loads will be connected to the 12V dc panel as shown in Fig. 1b.

The data acquisition unit, (DAC) gets the analog in puts representing the sky clearness index (X1), Load factor (X2) and the current state of charge of the battery (X3). The control system provides digital outputs in the form of Y1, Y2, Y3 and Y4. The first three of the outputs will be used to actuate heäters H1, H2 and H3 respectively to utilize the surplus SPV energy, by determining the state of charge of the battery (SOC) after the current time step. The out put Y4 controls the dc load.

2. The Case Study

A high-rise sub-urban residential building that faces problems of frequent power cuts coupled with inadequate and unsafe drinking water is considered in the present study. Typical daily average electrical demand of the household is 20 kWh out of which 4 kWh is the essential load: 2 lights, 2 fans and one refrigerator to keep running even during the utility power-cuts. Also, at least 50 liters of drinking water per day (LPD) must be made available to the residence even while the utility water supply is shut down. We propose a small scale integrated system consisting of a photovoltaic module (SPV) coupled with a roof top solar still (Fig.1a) for this typical remote suburban building, near Delhi. The roof-top solar still will distil water taken from the utility water supply mains, directly by the incident solar radiation as well as by the waste heat extracted from the SPV with the help of the heat exchanger. The surplus electrical energy converted by the SPV module will also be used for distillation of the drinking water and ensure that the available solar energy is most efficiently utilized.

A portion of the out coming water from the heat exchanger will be supplied to the top of the glass cover of the solar still where it will flow on the upper surface and evaporate by direct contact with the atmospheric air. The water cooled by evaporation will go back to the heat exchanger. The evaporation process will also keep the condensing surface of the solar still cool and thus increase the distilled- water-yield as shown by one of the present authors in [4]. Another advantage during the summer will be in the form of reduction of heat flux entering through the roof, leading to the reduction in cooling load of the building.

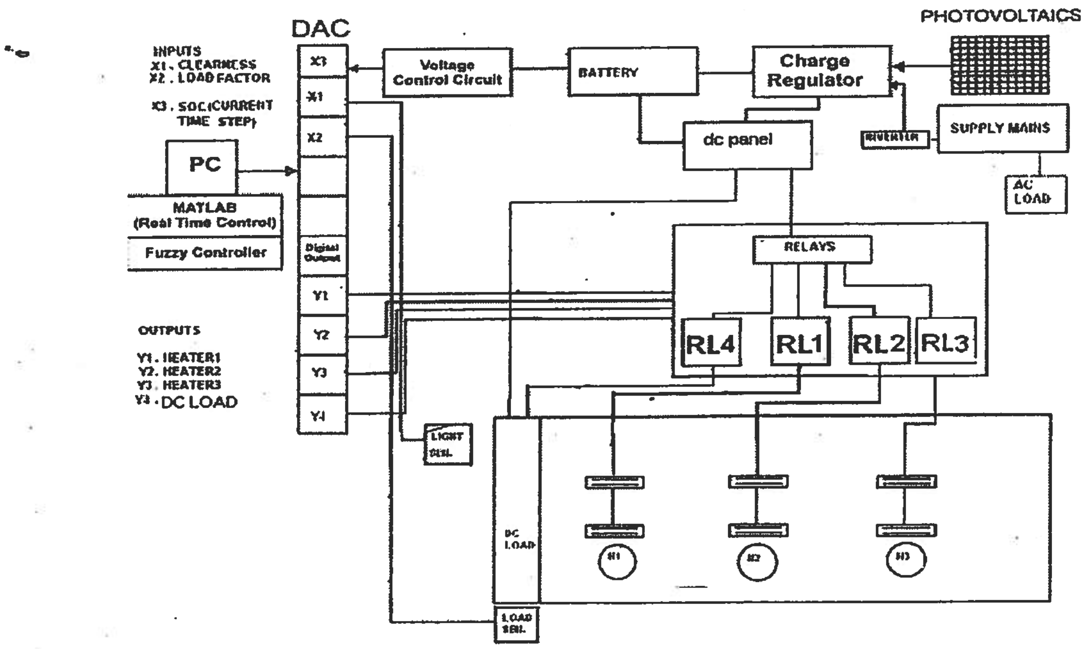

Fig. 1b: A schematic diagram showing the distribution of electrical energy generated by the SPV and the component of energy taken from the utility mains. A real time controller based on fuzzy logic is also depicted

2.1. The Electronic Cards for the Computer

The objective of the controller is to maintain the optimum level of state of charge, while utilizing the electrical energy generated by the SPV. The computer cards are designed for controlling the heater elements, measuring the outdoor lighting level, the battery voltage level, the dc load current and providing isolation between PC and the system as shown in Fig.1b. The Relay control card is designed with five single pole double throw (SPDT) relays which can be driven with the digital out puts (Fig.1a). The first three relays are used for controlling the heaters and remaining two relays select between the SPV and the AC supply mains (through the inverter). The light sensing circuit is designed for measuring outside lighting level.

An algorithm to calculate free energy (available for heating) is given below

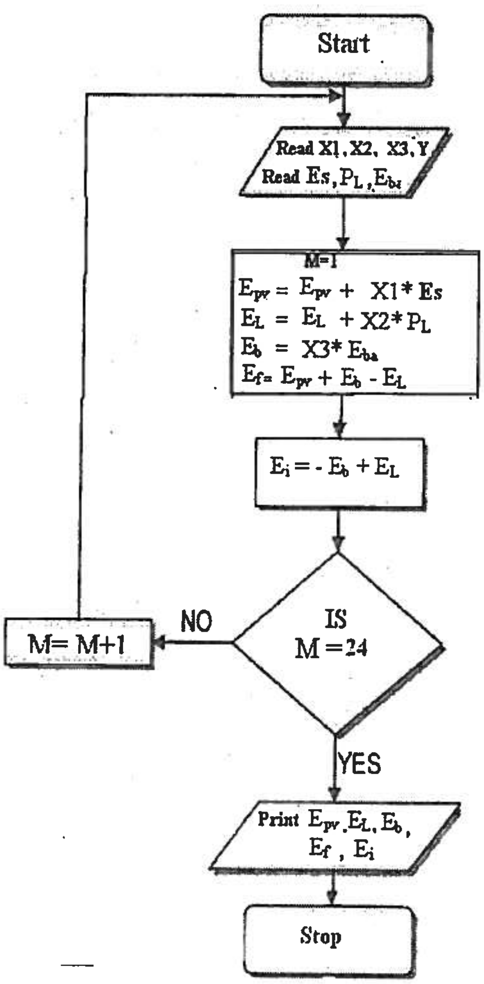

Fig.1c: An algorithm to calculate diurnal values of various components of energy in the system.

2.2 Hierarchy in the Proposed Fuzzy Control System

The proposed system is divided into three hierarchical levels. The level1 selects the hour of the year (h), as the current time step. Crisp values of the three inputs (X1, X2, X3) which are functions of time (the current hour of the year) are taken from the respective sensors (shown in Fig. 1b) for the fuzzy logic based controller (FLC). The out put (Y) of the FLC is a crisp value of free energy available for the heaters (inside the distillation system). The Diurnal values of monthly average solar radiation are stored in the memory of the PC.

In the level 2 of the control system, the amount of 'free energy' available for the heating system is determined. This is the balance of SPV energy (if any) left after deducting the load energy and battery storage. The result of the level 2, determines control action for actuating heaters and storage of battery in level 3 of the hierarchy.

Typical conditions of sky in the climatic region of Delhi were taken into consideration in determining the clearness Index (CI). (Experimentally, a light intensity meter will be used to record and provide the current value of CI. Weather data for Delhi, for the month of June has been taken from the Hand book [17]. The load factor will vary during the 24 hours period according to the actual requirements of the household. An ammeter can easily sense the real time instantaneous values of the load. Membership functions and fuzzy groups of sky clearness index, load factor and SOC are shown in Fig. 3

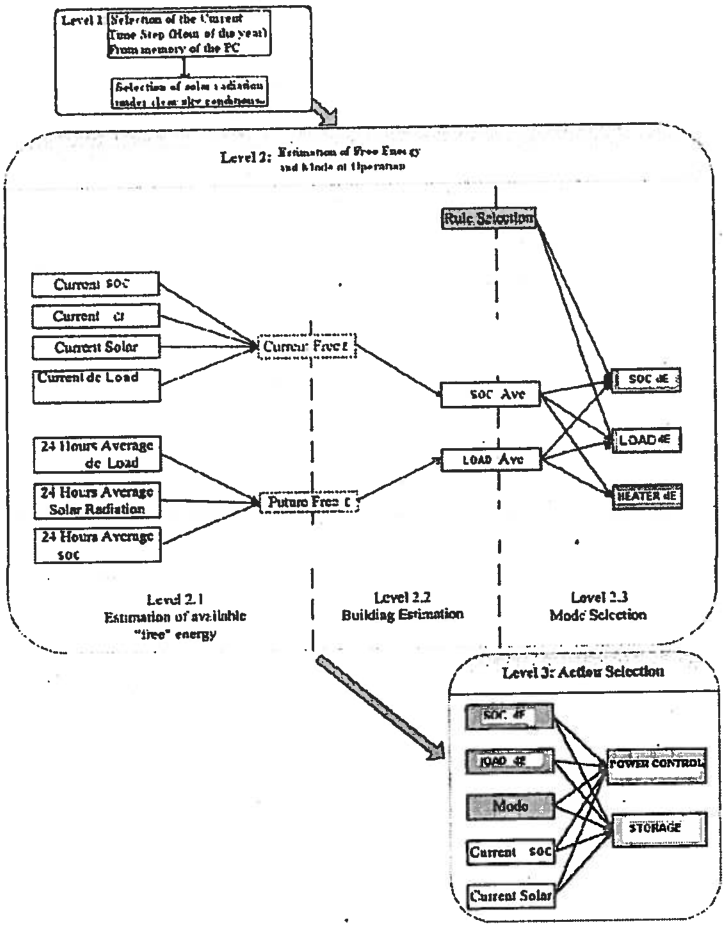

Fig.2: Three levels of hierarchy in the proposed FLC

3. Designing of Fuzzy Logic Controller

Figure 3 shows the schematic diagram of the proposed control system. There are three inputs: sky clearness (X1), load factor (X2) and the state of charge (X3) of the battery. The analog voltage signals representing the inputs are processed, amplified and converted to digital values and then fed to the FLC which produces a single output as shown in the figure. The multiplexer produces the desired out put signals to control the dc load, battery and the heaters corresponding to the inputs.

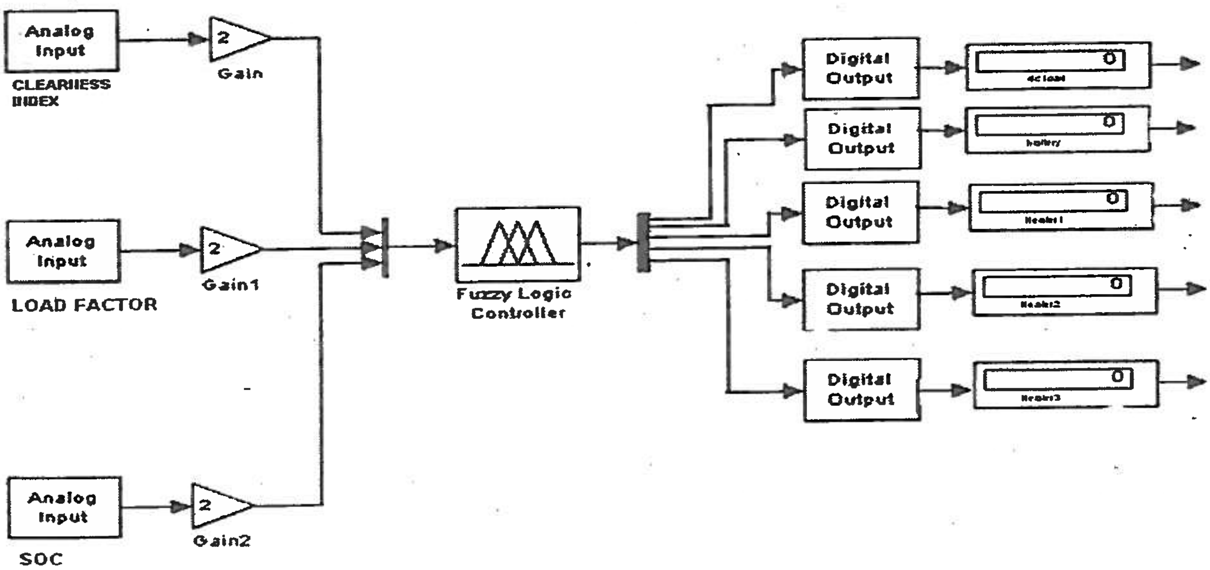

Fig.3: Schematic diagram of the Fuzzy logic based controller

3.1 Determining the Fuzzy Logic Rules

Fuzzy logic rules are determined on the basis of experts' decision or experimental observations, such as the following:

Rule 1: If sky is almost dark (X1=0) and load is small and battery charge is very low (X3=0) then no free energy is available for heating.

Rule 2: If sky is partly clear and load is small and battery charge is low then a small amount of free energy is available for heating.

Rule 3: If sky is bright and load is small and battery charge is medium then a sufficient amount of free energy is available for heating.

Rule 4: If sky is bright and load is small and battery charge is fully charged up then a large portion of free energy is available for heating.

In the present study the following four sets of weather conditions are taken into consideration:

-March, April and May when the sky is generally clear and solar radiation is high. A large part of electrical energy is available for distillation.

-June, July and August when the sky is generally cloudy and solar radiation is high. A smaller part of electrical energy is available for distillation.

-September, October and November when the sky is generally clear but solar radiation is not so high. A small part of electrical energy is available for distillation.

-November, December and January when the sky is not generally clear and solar radiation is low. A very small part of electrical energy is available for distillation.

Besides the above seasonal variations, clearness of sky largely depends on the clouds, dust etc. Hence the solar energy available for photovoltaic conversion and thermal treatment of water vary from hour to hour. This also affects the electrical load of the house hold such as the lighting, cooling and refrigeration. So, our fuzzy variables X1, X2 and X3 as also the fuzzy rule base vary from hour to hour. We have considered 112 fuzzy rules in this study.

Fig. 3.2 depicts 27 rules for the months of June, July and August. The three normalized input variables, sky clearness index (X1), load factor (X2) and state of charge of battery (X3) along with the corresponding output variable the corresponding output representing the available free energy (Y) are clearly shown in this diagram. Figures 4a and 4b show the Fuzzy membership plots for the above inputs and out put respectively. Figs. 5a,b,c depict values of output Y for different combinations of X1, X2, X3

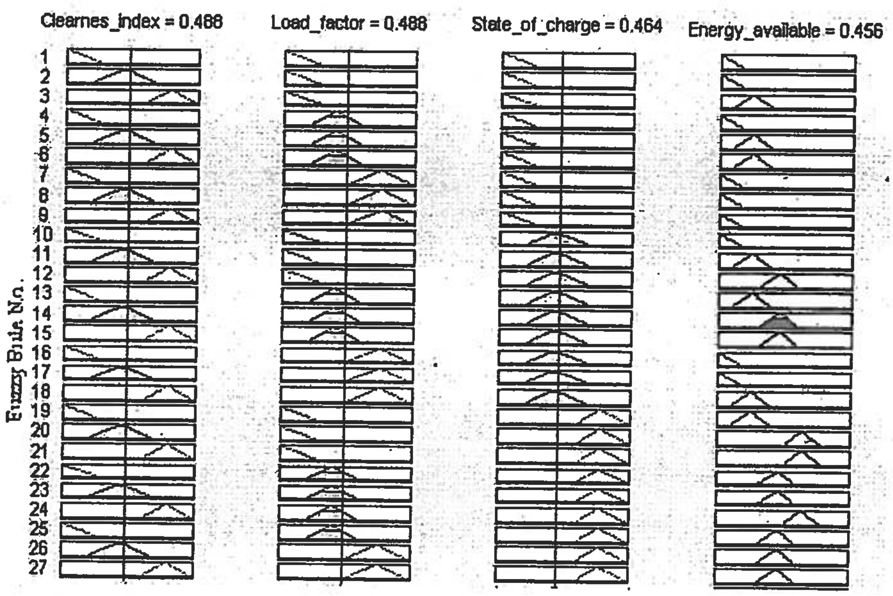

Fig. 3.2: Fuzzy Rule base depicting 27 rules for the months of June, July and August

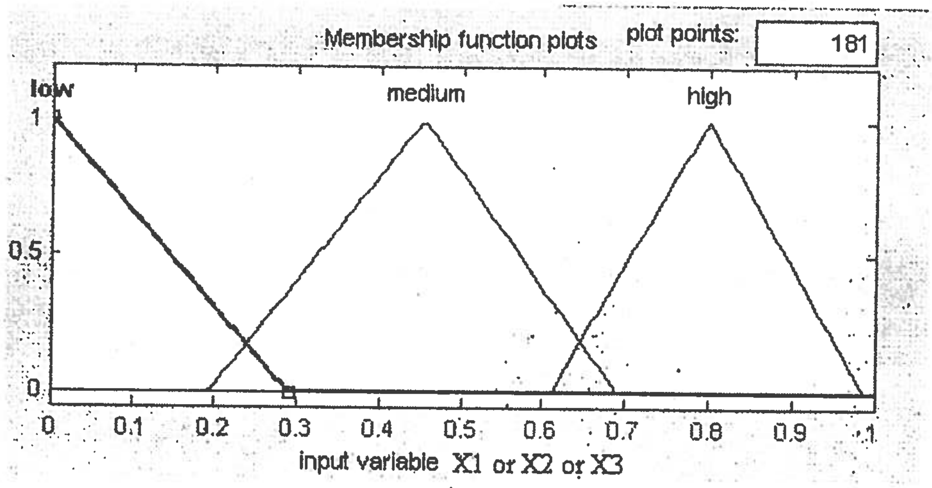

Fig. 4a: Fuzzy membership plot for input variable, (X1 or X2 or X3)

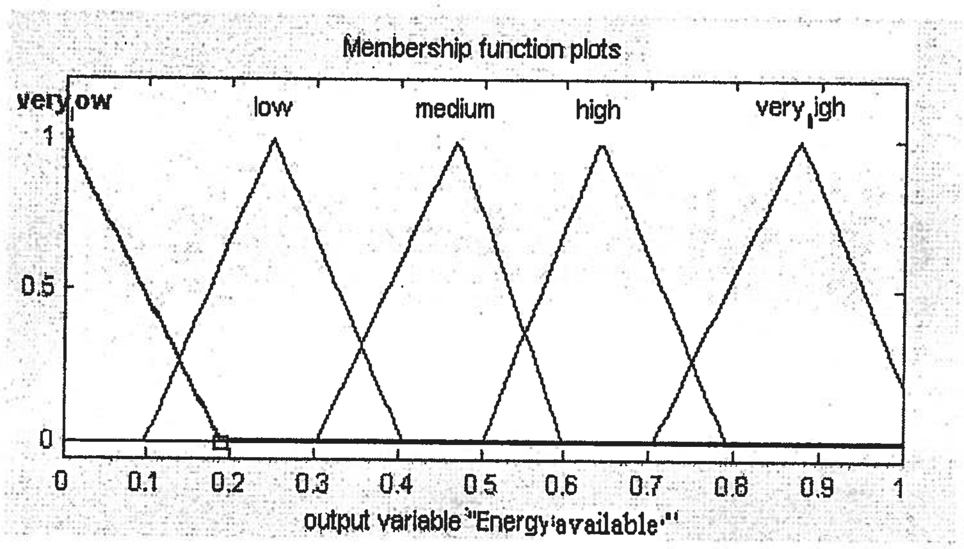

Fig. 4b: Fuzzy membership plot for output variable, Y

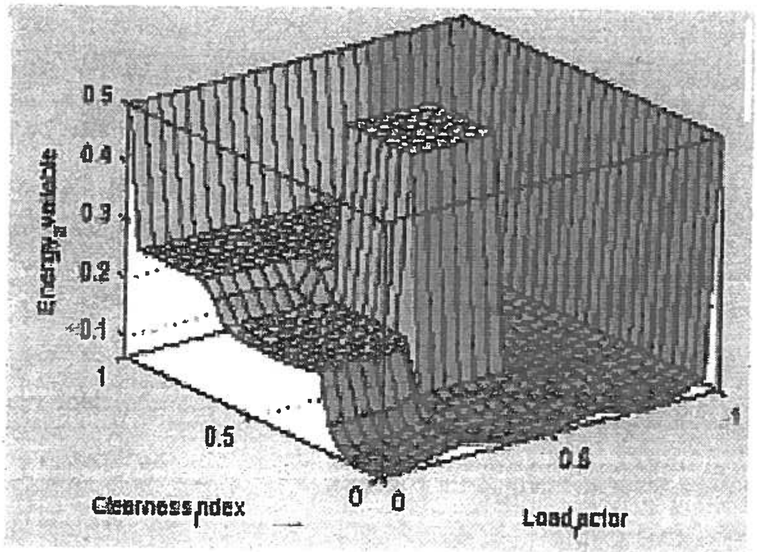

Fig.5a Values of output variable Y for different combinations of X1 ,X2;keeping X3 constant =0

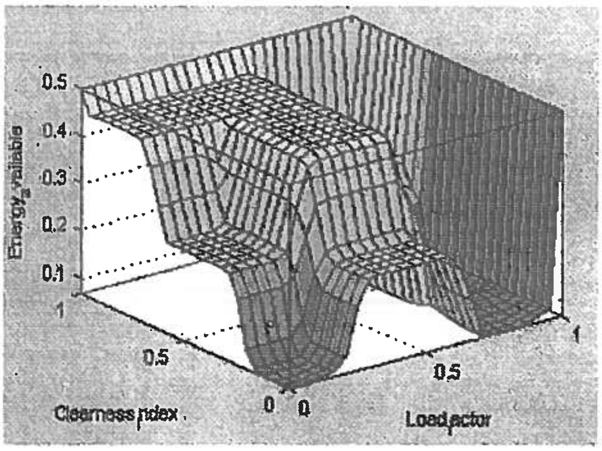

Fig.5b Values of output variable Y for different combinations of X1, X2;keeping X3 constant =0.5

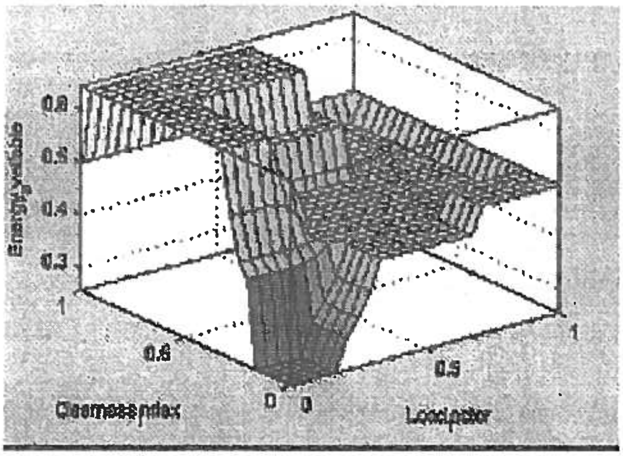
Fig.5c Values of output variable Y for different combinations of X1, X2;keeping X3 constant =1.0

The results of simulation are tabulated in Table 1.

Table 1: The Results of the simulation showing the amounts of solar energy collected by the SPVmodule and the free energy available in the proposed system in Wh.

TIME STEP(h)	ES	CI	LF	COP	E_{PV}	E_L	Ef	Eb
1	0	0	0.8	0.1	0	128	0	-128
2	0	0	0.7	0	0	128	0	-128
3	0	0	0.7	0	0	128	0	-128
4	0	0	0.6	0	0	128	0	-128
5	0	0	0.5	0	0	128	0	-128
6	52	0.1	0.4	0.2	5	128	0	-123
7	236	0.15	0.6	0.2	35	128	0	-93
8	488	0.2	0.7	0.2	98	128	0	-30
9	734	0.3	0.8	0.3	220	128	0	92
10	946	0.6	0.8	0.4	568	128	350	90
11	1090	0.8	0.8	0.5	872	128	350	394
12	1160	0.9	0.8	0.6	1044	128	350	566
13	1170	1	0.8	0.8	1170	128	350	692
14	1011	1	0.8	0.9	1011	128	350	533
15	920	0.9	0.8	1	828	128	350	350
16	696	0.9	0.8	1	626	128	350	148
17	458	0.8	0.8	0.9	366	128	350	-112
18	229	0.6	0.9	0.8	137	128	350	-341
19	51.8	0.5	1	0.7	20	220	350	-550
20	0	0.1	1	0.6	0	240	0	-240
21	0	0	1	0.5	0	240	0	-240
22	0	0	1	0.4	0	240	0	-240
23	0	0	0.9	0.3	0	128	0	-128
24	0	0	0.8	0.2	0	128	0	-128
					7000	3500	3500	0

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Conclusions:

A control system based on Fuzzy logic has been designed for an integrated small scale energy system. It will provide electrical energy converted by the solar photovoltaic module to meet the essential load requirement. Under the conditions considered, fifty percent of electrical energy is available for water distillation. However, under more cloudy conditions entire amount of the SPV energy will be utilized by the electrical load only and free energy may not be available at all. The amount of water that can be distilled with 3.5 kWh will be about 5 liters per day.

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