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A Systematic Approach For Storage Free Smart Energy Management With Frequency Control In Hybrid AC Micro Grid System

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Abstract—This paper provides a systematic coordinated control scheme for energy management in hybrid photo voltaic(PV), fuel cell (FC) and diesel engine generator (DEG) in an AC micro grid without any storage like batteries or flywheel for frequency regulation. The PV output is controlled by derating of PV and then it is coordinated with the other distributed generators (DG's) thereby participating in frequency regulation following a load demand or disturbance in the system. The maximum power delivery to the load is assured by an adaptive neuro-fuzzy inference system (ANFIS) based on maximum power point tracking (MPPT). The overall system is controlled by micro grid central controller. The scheme is modeled using MATLAB.
Index terms—active power control, ANFIS, distributed generation(DG), diesel generator, energy management, frequency regulation, fuel cell, microgrid, maximum power point tracking, neuro fuzzy controller, solar photovoltaic(PV).

I. INTRODUCTION

In any power system like micro grid the system frequency must be maintained at its nominal value following a load demand or any disturbance for stable operation of the system. Any generator is said to participate in frequency regulation if its output varies according to the load demand. The frequency regulation in conventional power system is provided by the automatic generation control (AGC) which maintains a balance between the load demand and power generation. But in system like micro grid the frequency regulation is hard to implement since there are no rotating part in the system with sources like PV and fuel cell. The diesel generator being a rotating machine can participate in frequency regulation however the PV generator and fuel cell cannot participate in frequency regulation.

To extract maximum power from PV, many maximum power point tracking mechanisms are used [1]. Despite the load variations the PV will always extract maximum power from the panel and it can't take part in frequency regulation. Thus providing real power reserve in PV is a tough task, hence for the sources like PV and fuel cell, battery storage is used for frequency regulation purposes. A wide range of literature survey provides a lot of schemes for frequency control using batteries and capacitors. In [2] authors have done performance analysis on battery storage devices and concluded that they are financial burden on a system. The charging and discharging control scheme is proposed in [3]. Micro grid controlled using PI controller is analyzed in [4].In [5-8] battery storage along with renewable is provided for solving various issues like frequency regulation, voltage unbalance, output leveling etc. But PV participating in frequency regulation is rare. In this paper PV is made to participate in frequency regulation by deloading of PV [10] and the derated power will be used to maintain the nominal frequency in the system. A recent technique is used for MPPT; Adaptive Neuro Fuzzy controller is used for MPPT in this paper. The duty cycle of the DC-DC converter is varied to control the output of the PV generator [11]. The PV generator output can be selected by this process, it is then coordinated with the other hybrid sources; Fuel cell and Diesel generator. PV output is used first, then Fuel cell followed by the Diesel generator. The main source is PV; FC and DEG are used when there is an increase in load demand. The overall scheme is controlled by the Micro Grid Central Controller (MGCC). The MGCC coordinates and controls all the units in the Micro grid.

In this paper, the description and modeling of sources is carried out in section II. The system model and working of MPPT, Derating of PV is discussed in section III. In section IV overall control scheme is explained and the simulation outputs are described in section V. Finally the conclusion is drawn in section VI.

II. HYBRID SOURCES

A. PV Module

Solar cell is the basic part in the PV system; its equivalent is represented by a single diode mathematical model. It consists of photocurrent source I_{ph}, a nonlinear diode, internal resistance R_s and R_{sh} as shown in Fig.1. The relationship for the current and voltage in the solar cell equivalent can be given as

$$I = I_{ph} - I_s\left(e^{\frac{q(V+IR_s)}{AkT}} - 1\right) - \frac{V+IR_s}{R_{sh}} \qquad (1)$$

Where, I_{ph} is photocurrent; $I_s$is diode saturation current; q is coulomb constant ($1.602e^{-19}$C); *k* is Boltzmann's constant ($1.381e^{-23}$ J/K); T is cell temperature (*K*); *A* is P-N junction ideality factor; R_s and R_{sh} are intrinsic series resistances. Photocurrent can be given as

$$I_{ph} = \left(\frac{S}{S_{ref}}\right)\left[I_{ph,ref} + C_T\left(T - T_{ref}\right)\right] \qquad (2)$$

Where, S is the solar radiation (W/m^2); S_{ref}, T_{ref}, $I_{ph,ref}$ is the solar radiation, cell absolute temperature, photocurrent in standard test conditions; C_T is the temperature co-efficient (*A*/*K*).

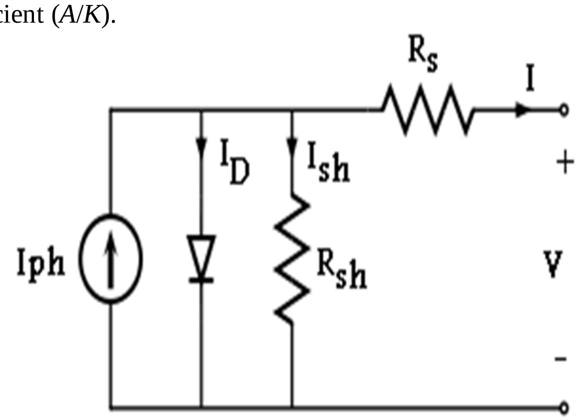

Fig.1. Equivalent circuit of solar cell

The solar cells can be arranged in series or parallel to obtain PV module.

A. Fuel cell

Fuel cell is an electrochemical device, which converts chemical energy into electrical energy. Unlike conventional batteries, fuel cells need not be recharged. But continuous fuel supply must be provided to the cell. The fuel cell consists of anode, cathode electrodes and electrolyte. Hydrogen is supplied as fuel to the cell and oxygen from air acts as oxidant. When hydrogen is supplied to the anode, it is oxidized to produce electrons and positive ions. The electrons produced reaches the cathode through electrolyte and the positive ions react with electrons to give water and carbon dioxide recombining with oxygen in the air. The fuel cell block is designed using fuel cell stack from the MATLAB Simulink library. Electrolyzers provide constant H_2 supply to the cell. Proton Exchange Membrane electrolyzer (PEM) is used in this model. The Proton Exchange Membrane Fuel Cell (PEMFC) has fast start up since no running liquid is used and it is easier to operate. The power density of PEMFC is also high. Hydrogen provided by electrolyzers can also be used in compressed form.

B. Diesel Generator

Diesel generator used in this model with speed governor, excitation controller and synchronous generator is being taken from MATLAB/Simulink SimPowerSystems toolbox that is based on IEEE standard 421.5

III. SYSTEM MODEL

The Micro grid central controller (MGCC) controls the overall scheme. The MGCC has information about the grid, hybrid sources generation and the load demand, it coordinates the overall scheme. The overall system scheme is shown in fig.2. PV is made controllable by derating of the output power and it is used as a reserve. It is explained in the following section.

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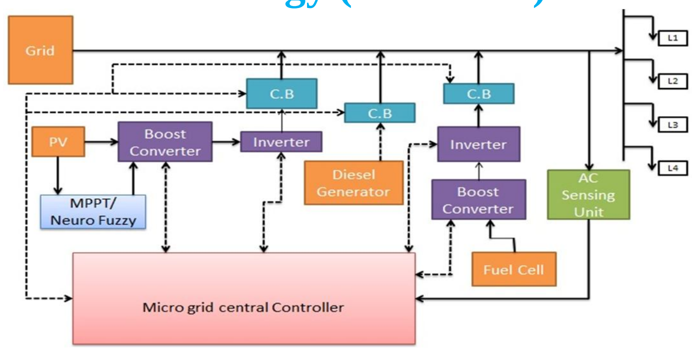

Fig.2. Block diagram of hybrid micro grid system

A. PV Generator

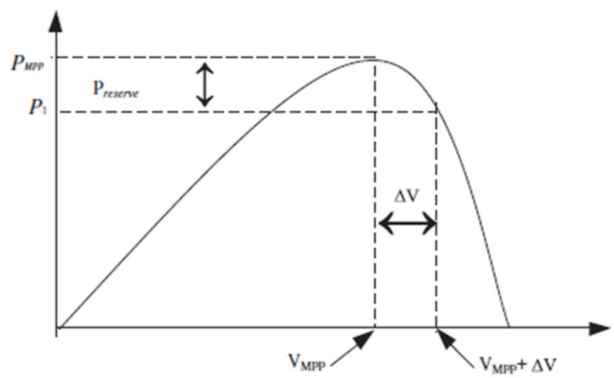

Fig.3. Deloading of PV

The PV is always modeled to track maximum power from the panel, but it can be made to operate away from the maximum power point by increasing its panel voltage beyond the maximum voltage. When the voltage is increased beyond the maximum voltage the power will reduce from its maximum point. Thus providing a real power reserve, that can be used for the frequency regulation. From Fig.3 It can be seen that when the voltage is increased beyond V_{MPP}, the power is reduced to P_1 from P_{MPP}. The voltage is increased to V_{mpp}+□V, the power $P_{reserve}$ is kept aside and can be used later for frequency regulation, when there is an increase in demand.

B. Maxmimum Power Point Tracking(MPPT)

The proposed ANFIS controller employs new scheme for the tracking of maximum power, it does not need details of the exact model. Maximum power is obtained by varying the duty cycle of the DC-DC converter. The block diagram of the MPPT tracking by ANFIS is shown in Fig.4.

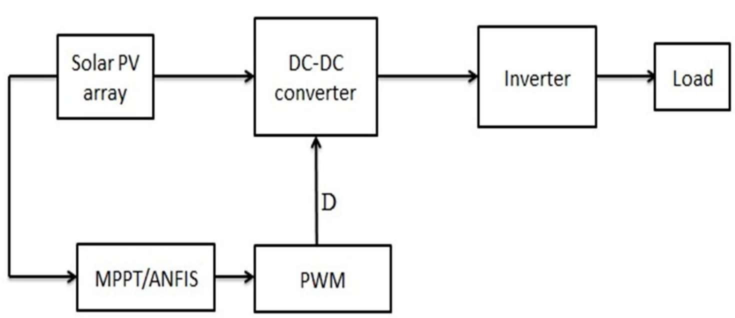

Fig.4. Block diagram of MPPT tracking

C. Fuzzification

Fuzzy controller has three stages, Fuzzification, Defuzzification and Inference. It can be described as in Fig.5.

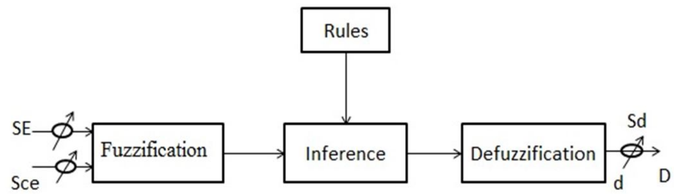

Fig.5. Fuzzification

The fuzzy logic consists of two inputs and one output. Error (E) and change in error (CE) are given as inputs to the fuzzy controller. The output is □D, change in duty cycle. Fuzzy rules are given in Table.1.

$$E(K) = \frac{P(K)-P(K-1)}{V(K)-V(K-1)} \quad (3)$$

$$CE(K) = E(K) - E(K-1) \quad (4)$$

D. Inference

The description of rules is as NB (negative big), NS (negative small), ZE (zero), PB (positive big) and PS (positive small).E indicates the operating point on the left or right of MPP on the P-I characteristic. The P-I characteristic of PV can be seen from the Fig.3. The Inference rule sets are given in Table.1.

Table.1. Fuzzy Rule Set

E \ CE	NB	NS	ZE	PS	PB
NB	ZE	ZE	PB	PB	PB
NS	ZE	ZE	PS	PS	PS
ZE	PS	ZE	ZE	ZE	NS
PS	NS	NS	NS	ZE	ZE
PB	NB	NB	NB	ZE	ZE

From the rule table if the error E is taken as PB, the change in error (CE) as NB then ΔD is PB. The slope E must be brought to zero to track MPP. E denotes the MPP, whether it is on the right or left side of the P-I characteristic. CE denotes the direction in which the point is moving. The duty ratio is increased or decreased according to slope E, if E is away from the MPP then duty ratio is increased. Thus the MPP is tracked by controlling the E and CE. Based on the rules given in Table.1, membership functions are shown in Fig.6, rule sets are framed in the Fuzzy logic which can be seen from Fig.7, the and the surface viewer is shown in Fig.7.

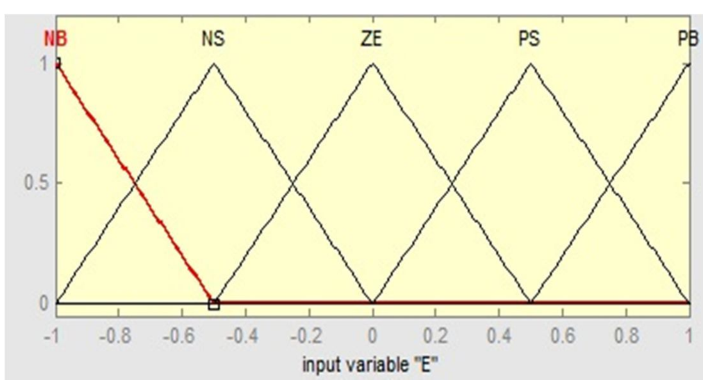

Fig.6. Membership function of E

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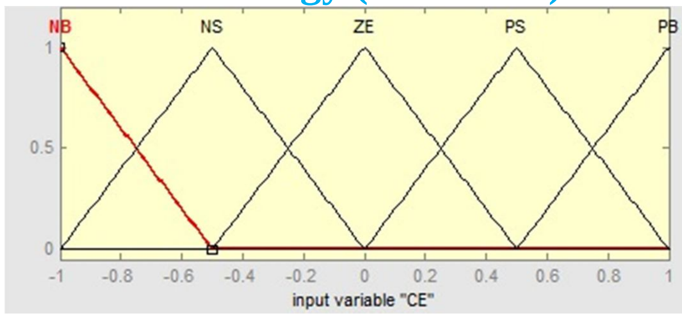

Fig.7. Membership function of CE

There are 25 rules in the rule viewer, which are framed using the Table.1; the □D varies with change in E and CE. When slide viewer is moved corresponding duty ratio value is obtained.

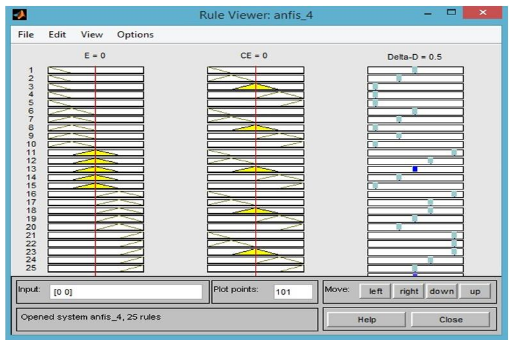

Fig.6. Rule viewer in Fuzzy

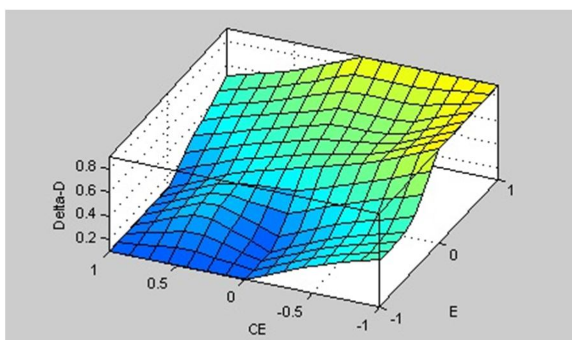

Fig.7. Surface viewer obtained from Fuzzy

E. Defuzzication

To get a defined output the inferenced values must be combined and Defuzzification should be done. The process used here is Centre of Area (COA) method. The final fuzzy set is then obtained; it is converted to normal value D from scaled value S_d, the expression is described as follows

$$\Delta D = \frac{\sum_{j=1}^{n} \mu(\Delta D_j).\Delta D_j}{\sum_{j=1}^{n} \mu(\Delta D_j)} \qquad (5)$$

$$D(K) = D(K-1) + S_D.\Delta D(K) \qquad (6)$$

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IV. OVERALL CONTROL SCHEME

The nominal frequency varies with change in load, it is denoted by □f. Frequency is dependent on the difference between the generation and load demand.

$$\Delta P_S = \Delta P_T - \Delta P_D \qquad (7)$$

$$\Delta F = \frac{K_{PS}}{1+T_{PS}} \Delta P_S \qquad (8)$$

If the □f>0; then MGCC activates the generation of the sources. The generation of the hybrid system is increased to match the load. The nominal frequency is monitored and the information is send to the MGCC. The change in frequency is measured and the generation is increased according to that. Normally the grid will be supplying the load demand, but when there is a deficit in power, supply will be provided from the Micro grid to meet the load demand. Thus the power balance is maintained in the system thereby keeping the nominal frequency constant. During a demand, PV supplies the load first; the deloaded power is fed to the load. When the PV output is deployed, then power is drawn from fuel cell and if that power is too deployed, then during peak demand; diesel generator will supply the load. After all the supplied is used, the MPPT will be activated in the PV and reserve power in PV is used.

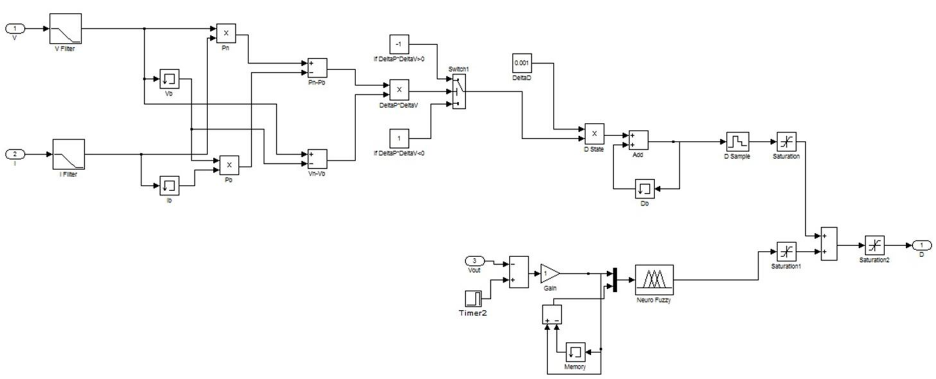

Fig.8. Simulink of Maximum Power point Tracking

The frequency is measured and monitored by the AC sensing unit, which will send the information to the MGCC. According to the received data, the MGCC decides whether the frequency service should be activated or the generation control should be activated.

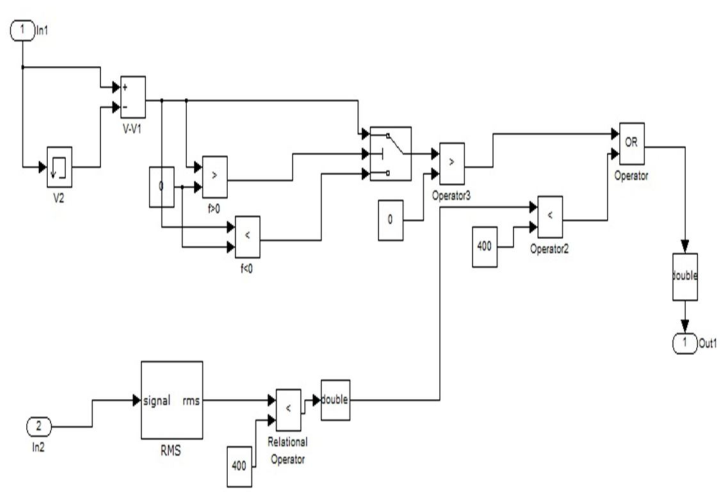

Fig.9. Simulink of AC sensing unit

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V. SIMULATION OUTPUT

The Grid supplies a constant load of 0.4KW first, and then the load demand increases by 70W. There occurs a power deficiency and hence the power generation is activated. The PV supplies the power increase of 70W and then the third load is connected to the system which is 15W, it is supplied by activating the Fuel cell. When the demand is increased by 15W again, it is supplied by the diesel generator. Thus the generation is activated according to order, PV is activated first; followed by the FC and then by the DEG. Diesel generator is activated only during peak hours, since its operating cost is high.

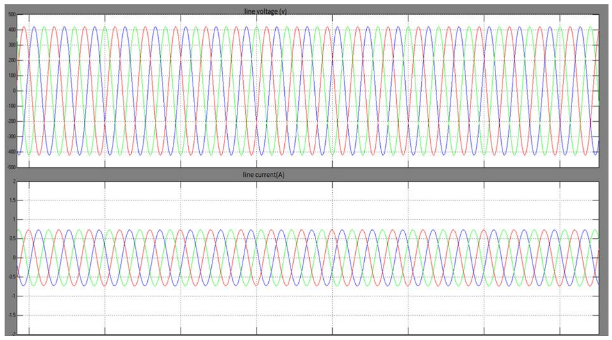

Fig.10. Grid output

The Grid voltage and current waveforms are shown in Fig.10, the frequency response of the system when hybrid system is not connected is shown in Fig.11. From which it can be seen that there is a visible frequency drop followed by a load demand. It is rectified when the hybrid is added to the system, maintaining the power balance in the system.

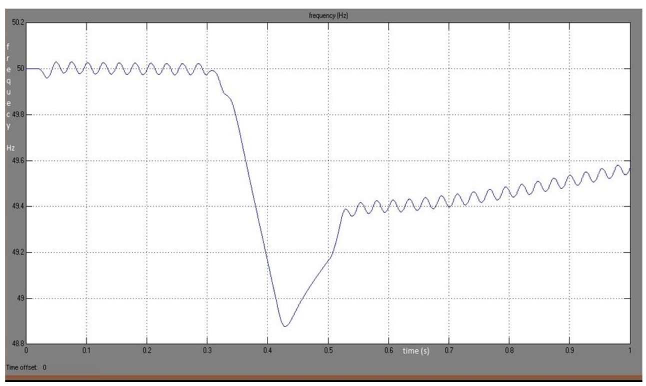

Fig.11. System frequency without hybrid connected

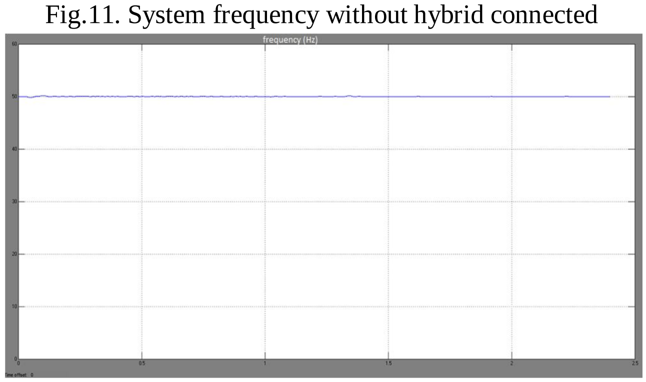

Fig.12. Frequency with hybrid connected

The overall system output is as shown in the following Fig.13 the plot shows the coordinated scheme of PV, Fuel Cell and the Diesel generator. The power drawn from grid and the other generators is shown in Fig.13.

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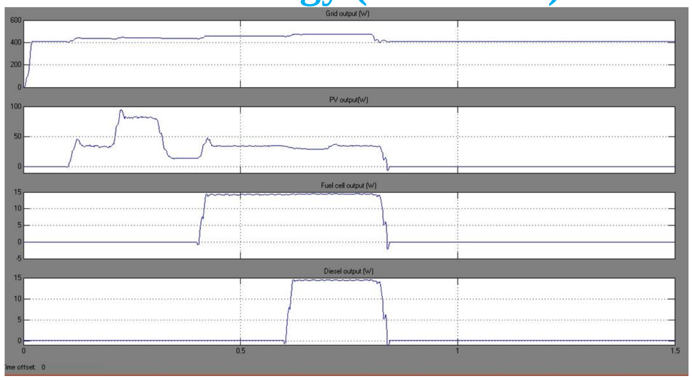

Fig.13 coordinated control of hybrid system

VI. CONCLUSION

In this paper the frequency is maintained constant throughout the system operation following a load demand by coordinating the hybrid sources like PV, Fuel cell and Diesel generator. The PV output is deloaded and the remaining power is used as reserve. The reserve power is used when the frequency regulation is needed. Thus PV is made to participate in frequency regulation like conventional generators. A recent advancement in MPPT is used for obtaining maximum power from the PV. The Duty cycle of the DC-DC converter is varied to control the output of the PV generator. The exact detail of the system is not needed; the Fuzzy rules are framed to track maximum power under any varying condition.

The system operation follows a specific scheme; the power will be supplied to the load mostly by the PV, then by the Fuel cell followed by the Diesel generator. The Diesel generator is operated only during peak demand.

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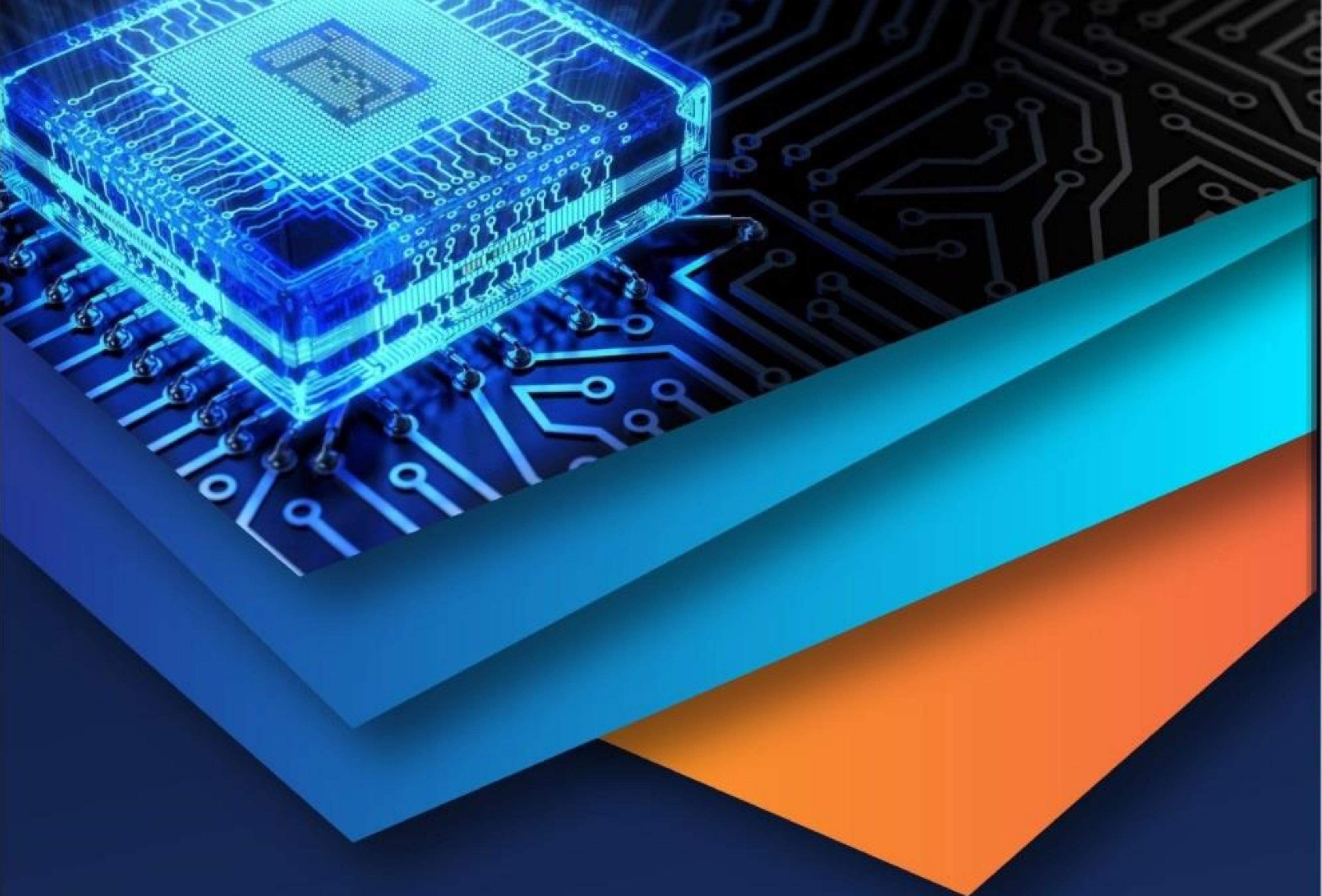

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