*International Journal of Research in Engineering and Science (IJRES)*
*ISSN (Online): 2320-9364, ISSN (Print): 2320-9356*
*www.ijres.org Volume 4 Issue 4 ǁ April. 2016 ǁ PP. 46-57*

# Technological Analysis of a Solar-Wind-Battery-Diesel Hybrid Energy System with Fuzzy Logic Controller

SK. A Shezan[a], Md. H. Delwar[b], Md. T. Anowar[c], Md. D. Islam[d], Md. A. Kabir[e], Md. H. Reduanul[f], Md. M. Hasan[g]
[a]*Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603, Kuala Lumpur, Malaysia.*
[a,b,c,d,e,f,g]*Department of Electrical and Electronic Engineering, Faculty of Engineering, Uttara University, Dhaka, Bangladesh.*

**Abstract:-** *Viable usage of force is more critical than era of force since power lack is the real issue at present in India. It leads numerous businesses to use the diesel generator comes about contamination and request to fossil fuel. These days numerous businesses and government interests on renewable vitality. A sun based wind crossover vitality life form assumes a urgent part today in renewable power assets since it uses wind essentialness united with sun based imperativeness to persevere alone power source that is unsurprising and dependable. This paper proposes compelling imperativeness organization controller for sun based vitality framework and wind mixture renewable power system for telecom business wanders. In power frameworks separated from power era overseeing of force without wastage is basic. This paper proposes Compelling power association controller fated by Fluffy Rationale Controller (FLC) to screen the drive from all heap stipulate and belonging reliably and to oversee whole half and half vitality plot. Fluffy rationale controller makes precise determination of sources in right timing. Fluffy Rationale has been utilized to speak to the most monetarily practical, powerful for remote zones and environment well disposed half and half vitality framework to bolster the telecom gadgets. Nonattendance of telecom devices consistently is unfathomable in current example. Major focus of this article is to give proceeds with energy to telecom stacks from off-framework sun based wind-Diesel mixture control framework with capable vitality stockpiling framework. It gives ceaseless power, convincing utilization of renewable vitality assets, upgrades life time of battery, minimized usage of diesel, diminish the emanation of $CO_2$ and GHG gasses. The whole examination has been done by MATLAB/Simulink.*

**Keywords:-** Fuzzy Logic Controller (FLC), Renewable Energy, Sustainable Development, Matlab, Feasibility, Hybrid Energy System.

## I. INTRODUCTION

An urgent search for alternative energy has become mandatory to meet the wide demand as the fossil fuel resources are depleting rapidly. Growing evidence of the global warming phenomena is another key reason to stop relying on fossil fuels. As the demand of energy is increasing, it has become essential to come up with alternative energy sources. At the same time, it is also needed to consider the environmental factors while meeting the excessive demand of energy [1]. Due to the availability and topological advantages for local power generations, researchers are considering solar and wind energy systems very promising for remote area power supply. Since oil crisis started in the early 1970s, utilizing solar and wind energy is cost-effective, attractive and increasingly significant. However, unpredictable nature and dependence on climate & weather changes, solar and wind energy may not fulfill the time distribution of load demand [2]. This shortcoming results in discarded batteries too early and affects the energy performance of system. The independent use of solar and wind energy resources may result in over-sizing that makes the design expensive. Due to periodical and seasonal variations, stand-alone solar energy system or wind energy system cannot provide power supply continuously. It is fortunate that by using these two energy resources in a proper combination, the problems can be overcome. It is possible to overcome the problem using one source to cover the weakness of another energy source. For certain locations, wind energy and solar energy got complementary characteristics [3]. Highly reliable power source can be offered by the hybrid solar-wind power generation systems with storage banks. Like radio telecommunication, the hybrid systems were preferred for remote systems. For grid-connection applications of updating existing single source system (Hydro, PV or Wind) into the hybrid system has become a recent trend. To design and analyze the hybrid systems become difficult for this complexity [4]. One optimum sizing method is important to utilize renewable energy resources in a more efficient way. Regarding investment and system power reliability, the optimum sizing process guarantees the minimum investment using full PV array, wind turbine, and battery bank. Economic objectives are involved in this type of optimization[5]. This optimization requires system's long-term assessments to ensure efficiency. G To reach a techno-economic optimum hybrid economic system graphical construction approach, probabilistic method, and artificial intelligence can be used. An optimum combination of the system reliability and the system cost are two major parameters must be searched for by them no matter what sizing and optimization technique are used [6]. A vital criterion in optimization is the expected reliability from a stand-alone hybrid system; the governing factor is the cost of the system if unlimited budget is not available. Therefore, to attain an optimum solution, they must study the relationship between system reliability and cost. This paper will concentrate on reviewing the current state of the local meteorological data generation, optimization and control technologies for the stand-alone hybrid solar–wind energy systems with battery storage and try to find what further work is needed [5].

Solar energy and wind energy is clean environment friendly. That is why they are referred as green energy. Energy sectors are attracted to these positive characteristics of renewable energy towards humankind. Positive Outcomes of renewable energy also attracted energy sector to reduce harmful gasses approximately 80% to 90% by using them on a larger scale. Weather, climate, etc. are unpredictable factors of nature on which renewable energy sources depend on [7]. This paper reflects the proposal to meet load in all season by using hybrid solar power system. Hybrid energy stations are proven technology that can help to supple energy to remote rural areas. It is also proven to be advantageous for decreasing the depletion rate of on renewable energy sources without harming the environment [8].

Distributed Generation (DG) refers to small power plants (a few watts up to 1MW) at or near the loads, operating in a stand-alone mode or connected to a grid at the distribution or sub-transmission level, and geographically scattered throughout the service area. Small .modular technologies for electricity generation are included in distributed generation. Both stand-alone mode and grid parallel mode use distributed generation technologies. Stand alone mode IPS supplies telecommunication load n this paper. Many industries are far away from a city in India. $0-60% residencies are also far away from the city [9]. Industries require telecom towers near them which are essential for the industries situated in rural areas. India is the second largest telecom market, and one of the fastest growing industries of India is telecom industry. According to Telecom Regulatory Authority of India (TRAI), telecom subscribers are increasing day by day. In December 2009, Indian telecom subscribers increased to 562.21 million [10]. In November 2009, it was 543.20 million. The growth rate was 3.5% that is significant. To meet the demand communication, increasing the amount of electricity is required by the telecom industry. Grid and burning diesel are the ways to meet the demand of electricity. There are 3, 10,000 telecom towers in India. 70% of the total towers are in rural areas of India. Diesel generators are meeting 60% of power requirements, and grid electricity is meeting the rest 40% [11]. Diesel generators consume about 2 billion liters of diesel to meet the demand every year [12]. The diesel generators are of 10-15 KVA capacity and consume about 2 liters of diesel per hour and produce 2.63 kg of $CO_2$ per liter. The total consumption is 2 billion liters of diesel and 5.3 million liters of CO2 is produced. For every KWH of grid electricity consumed 0.84 Kg of $CO_2$ is emitted. 0.84 Kg of $CO_2$ is emitted for every KWH of grid electricity consumed. $CO_2$ has emitted around 5 million tons due to diesel consumption. Around 8 million tons, $CO_2$ is emitted due to grid per annum [13].

# II. SYSTEM DESCRIPTION

## 2.1 Hybrid Renewable Energy System

In this paper hybrid power system is designed with two renewable energy sources like wind and solar are connected with conventional energy source. A stand-alone wind system with solar photovoltaic system is the best hybrid combination of all renewable energy systems and is suitable for most of the applications, taking care of seasonal changes. There are three types of integration available in IPS. They are DC coupled, AC coupled and Hybrid coupled. In an AC coupled, sources are connected to the AC grid where synchronization is required. Synchronization makes integration little bit complex. In DC coupled, sources are connected to the DC grid where synchronization is not required. So DC coupled system is very simple. In the Hybrid coupled system both DC and AC grid is used, it makes system complex and costly. In this paper since telecom load is selected DC coupled integration is proposed. Block diagram of Solar wind Hybrid system is shown in Figure 1.

In this paper IPS consists of solar, wind, Battery bank and diesel generator. AC supply produced by wind mill and diesel generator is converted to DC by diode rectifiers (AC/DC). All DC source avail is controlled by DC- DC converters, which makes DC suitable for telecom application. For DC-DC conversion SEPIC converter is proposed. In a wind source and diesel source SEPIC converter acts as a buck converter. In a solar power plant SEPIC converter acts as a boost converter. Battery bank is charged through charge controller with SEPIC boost converter. Battery bank discharging is controlled by selector switch. Dump load is connected to the grid to act as a load when the energy production is excess than load and state of battery is fully charged. In this proposed system Dump load is auxiliary battery bank to utilize the sources effectively. All sources and dump load are connected to the grid through selector switch. All selector switches are controlled by EEMC. Energy efficient management controller plays major role in selecting source to grid. Hybrid system provides reliable and sufficient supply to the load [14].

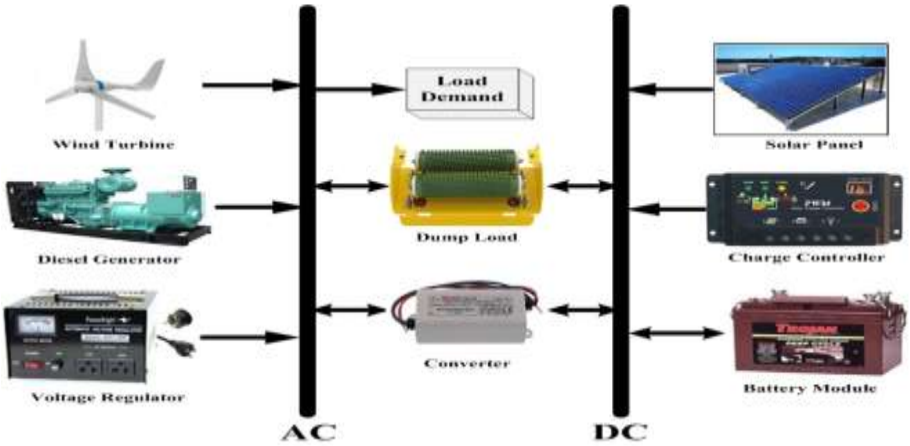


**Figure 1: A Complete hybrid solar-wind renewable energy system.**

### 2.2 Wind Power System

The wind turbine captures the winds kinetic energy in a rotor consisting of two or more blades mechanically coupled to an electrical generator. Permanent Magnet Synchronous Generator (PMSG) or Induction Generator (IG) performs as an alternator to produce electrical power. In this paper PMSG is preferred for wind power plant because of its high efficiency and power coefficient, Secure and stable operation, no need of slip rings and power factor correction condensers.

In this article a hybrid off-grid hybrid solar-wind renewable energy system has been designed with diesel generator and battery module as efficient energy storage system.

Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world. Additional benefits of fuzzy logic include its simplicity and its flexibility. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. Wind speed error 'E' and error change rate 'EC' are used as fuzzy input and the modulation index 'm' as fuzzy output. The degree of truth of E is configured as 7 degrees, all defined as (VN, N, LN, Z, LP, P, VP), and EC is configured as 3 degrees all defined as (N,Z,P) where VN,N, LN,Z, LP,P and VP represent very negative, negative, low negative, zero, low positive, positive and very positive respectively.
The energy extraction from the wind turbine can be calculated by the following equation.

$$P_m = 0.5\rho AC_p v^3 \qquad (1)$$

Where,
v Wind speed (m/s)
$\rho$ Air concreteness (Kg/m$^3$)
λ Wind velocity (m/s) t
A flounced area (m$^2$) (the wind turbines Power coefficient

The degree of truth of m are configured as 7 degrees, lies between (0,1). In this paper Sugeno type of fuzzy is proposed with Min-Max method fuzzification and weighted average method of defuzzification. In this paper 21 rules of fuzzy are proposed in this system. Surface view of the fuzzy to show the utilization of rules is shown in Figure 6, it shows that utilization of minimum area leads to quick response. The control rules are listed in Table I.

### 2.3 Solar Power System

The solar modules (photovoltaic –PV-cell) generate DC electricity whenever sunlight falls in solar cells. Solar radiation sustains all form of life on earth. According to estimates, sun radiates 1.74 x 10 $^{17}$ W of power per hour to earth the daily solar energy radiation varies from 4-7 kWh per m2 and there are 270-300 sunny days in a year. Single PV cell produces a rather small voltage that has less practical use. The real PV panel always uses many cells to generate a large voltage. The following parameters were used in the calculation of the net current of a PV cell. Saturation current of the diode, Io, Net current from the PV panel I, Light-generated current inside the cell $I_{L,}$ Series resistance Rs, which is internal resistance of the PV panel, Shunt resistance Rsh, in parallel with the diode, Rsh, is very large unless many PV modules are connected in a large system, Diode quality factor, n.

The energy calculation from the solar panel can be done by the following equation:

$$E = A \times r \times H \times PR \qquad (2)$$

Where,

*A* Net Area of solar module (m²)

A flounced area ($m^2$) (the wind turbines Power coefficient)

*E* Electrical energy (kWh)

*H* yearly standard global solar radiation

*PR* Performance Ratio

In an ideal cell Rs is 0 and Rsh is infinite. The net current of the PV cells is the difference between the output current from the PV cells and the diode current is given by.

I=IL-Io[e(q(V+IRs)/nkT)-1] (3)

Where V is the voltage across the PV cell, k is the Boltzmann's constant (1.381 x $10^{-23}$ J/K), T is the junction temperature in Kelvin, q is the electron charge (1.602 x $10^{-19}$ C), n is the diode ideality factor (1.62).

The maximum power point tracking is an essential and challenging controller in PV system because the energy produced in PV panel is based on irradiation which is not constant during the whole day. Since the irradiation is not constant the Voltage produced in PV is non linear with its current. It necessitates the MPPT to work effectively with non linearity and imprecise data. Conventional MPPT methods such as Hill climbing and P&O are popular for its simplicity and ease of implementation. But it does not produce speed and accurate control which are possible by using artificial intelligent controller like fuzzy logic controller. In this paper fuzzy logic controller is proposed for effective MPPT [11].

In this method of MPPT change in voltage and change in power is taken as input like incremental conductance method. Fuzzy logic controller of MPPT produces duty ratio as output. Pulses based on this duty ratio controls the switch in SEPIC. Inputs of the Fuzzy logic controller follow equations (4) and (5) [15].

$\Delta p=p_i-p_{i-1}$ (4)

$\Delta v=v_i-v_{i-1}$ (5)

Block diagram of the fuzzy logic MPPT is shown in Figure.7. Mamdani type of fuzzy is proposed in this paper. Inputs of fuzzy are represented as Δp and Δv. A degree of truth for inputs are7 and for output is 9. Membership functions of inputs are (NB, NM, NS, Z, PS, PM, PB) named as Negative Big, Negative Medium, Negative Small, Zero, Positive Small, Positive Medium and Positive Big. Membership functions of output are (NVB, NB, NM, NS, Z, PS, PM, PB, PVB) it is similar to the inputs except Negative Very Big and Positive Very Big. Figure 11, 12, 14, 15 and 16 shows the membership functions of inputs and output [16].

**Table 1: Control Rule for Solar MPPT.**

| Δp \ Δv | NB | NM | NS | Z | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NVB | NB | NM | NS | Z | PS | PM |
| NM | NVB | NB | NM | NS | PS | PM | PB |
| NS | NVB | NB | NM | NS | PS | PM | PB |
| Z | NB | NM | NS | Z | PS | PM | PB |
| PS | NB | NM | NS | PS | PM | PB | PVB |
| PM | NB | NM | NS | PS | PM | PB | PVB |
| PB | NM | NS | Z | PS | PM | PB | PVB |

Surface view of FLC is shown in Figure 7, 8, 9 and 10 Centroid method of defuzzification is proposed with 49 rules. Table 1 shows the rules of fuzzy logic controller.

Fine tuned Fuzzy controller produces better duty ratio compared to conventional controllers. It results better voltage control in SEPIC and produces controlled power.

**2.4 Battery Energy Storage System**

Storage of Energy produced by renewable energy based power system is very essential to provide a constant power to the load. The lead-acid battery is proposed in this paper for energy storage. It has two modes of operation charging and discharging modes. When the current to the battery is positive, the battery is in the charging mode. When the current to the battery is negative, the battery is in the discharging mode. The following parameters were used for modeling the battery. SOC varies linearly with Vocb (open-circuit battery voltage). $SOC_1$ is the initial state of charge, SOC (%) is the available charge. SOC m is the maximum state of charge. Ns are the number of 2 V cells in series. D (h_1) is the self discharge rate of battery. Kb (no unit) is the charging and discharging battery efficiency. As the terminal voltage of the battery is given by

$V_{bat}=V_1+IbatR_1$

Here $R_1$ is the equivalent resistance of the battery. $V_1$ and $R_1$ both depend on the mode of battery operation and have different equations. Battery current; Ibat is positive when battery is in charge (ch) mode and negative when in discharge (dch) mode. In charging mode, $R_1$ and $V_1$ are written as

R1=Rch= (0.758+7)

$V_1$=Vch= [2+0.148SOC (t)] ns

When the battery is charging.

In discharging mode $R_1$ and $V_1$ are written as,

$R_1$=Rdch= (0.19+8) (9)

$V_1$=Vdch= [1.926+0.124SOC (t)] ns (10)

**2.5 SEPIC Converter**

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. This type of converter is the optimum converter for renewable energy sources since source voltage fluctuates above and below the output voltage. Unlike Cuk converter, it produces output as in the same polarity of input.

Assuming 100% efficiency, the duty cycle, D, for a SEPIC converter operating in DCM is given by (10)

$D= (V_{OUT} +V_{FWD})/(V_{IN}+ V_{OUT} +V_{FWD})$ (11)

Where $V_{FWD}$ is the forward voltage drop of the diode. Since the average voltage across C1 is $V_{IN}$, the output voltage

$(V_O) = V_{S1} - V_{IN}$ (12)

SEPIC converters can acts as buck or boost converter. In a solar power plant and battery charging controller it acts as a boost converter. Condition to act as a boost converter is stated in (13)

$V_{s1}>V_{IN}$ (13)

In a wind and Diesel power plant it works in buck mode. Condition to operate in buck mode is stated in (14)

$V_{s1}<V_{IN}$ (14)

If $V_{S1}$ is less than double $V_{IN}$, then the output voltage will be less than the input voltage. If $V_{S1}$ is greater than double $V_{IN}$, then the output voltage will be greater than the input voltage.

Switching loss of power device (MOSFET) in a SEPIC converter is given in (15). In the proposed project, less switching frequency is selected for switching the power device. It reduces the switching loss.

**2.6 Diesel Generator**

In this paper diesel run generator is used as a standby power system. It is switched ON only when all the sources are individually or in combined conditions are not able to meet the load demand. In this condition controller activate selector switch automatically. Now the demand is met by DG and also battery charging continuously up to SOC of >95 %. This process is withdrawn if the main source is ready to supply to the load. Output of DG is AC; it is converted to DC through diode rectifier. Figure 2 shows the simulation model of DG system.

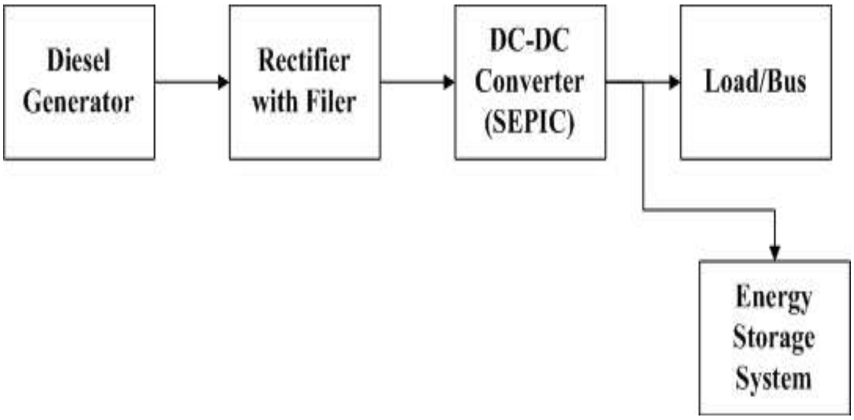


**Figure 2 : Block diagram of a diesel generator power conversion system.**

**2.7 Dump load**

In renewable power sources like wind excess power is produced during high wind velocity (over generation). Nowadays this power is dissipated in a dump load. Generally resistor acts as a dump load. The excess power is wasted in existing renewable power plant. Occasionally a case may happens that load is very low, power generation is high and battery bank is also in a full charge state. In that situation power source is cut off. So the power generated is not utilized. In this paper Auxiliary Energy Storage System (AESS) is proposed as a dump load. It gives solution to store the excess energy produced by the power plant. With the help of AESS capacity of energy storage system is raised and usage of diesel generator can be minimized.

**2.8 Load**

The proposed system is capable of handling DC load as well as AC load. The DC load directly receives power from DC bus. In case of AC load, the 3 phase IGBT based Hex bridge inverter is fed from DC bus. Inverter is controlled by pulse width modulation technique. Output of inverter is filtered by LC filter and pure sine wave is given to the load. Three phase voltage from filter is shown in Figure 3.

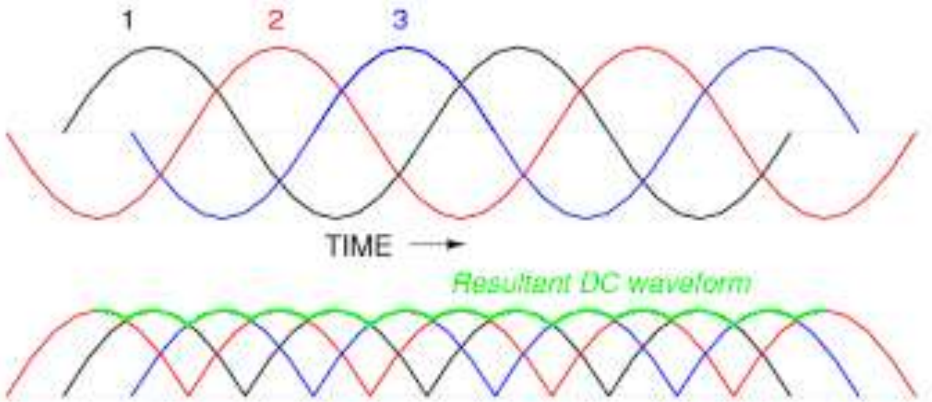


**Figure 3: Three phase voltage from filter.**

**3. FLC BASED EFFICIENT ENERGY MANAGEMENT CONTROLLER**

FLC based Efficient Energy Management Controller (EEMC) monitors the status of load, power generated by wind source and PV system, SOC of the battery and Dump load battery. It receives all sources existing power and load power. Depending on the load and available power generated by source, it selects individual source or combination of sources supply to the grid. It continuously monitors the SOC of battery and activates the charge controller when the battery does not supply the load and SOC is less than $SOC_m$. Battery and dump load battery discharging is limited to SOC minimum of 20%. Always battery is in the state to supply load. Block diagram of a fuzzy logic controller has shown in figure 4. Figure 5 and 7 also show the fuzzy logic controller operation. Figure 6 shows the surface view of the FLC in Matlab.

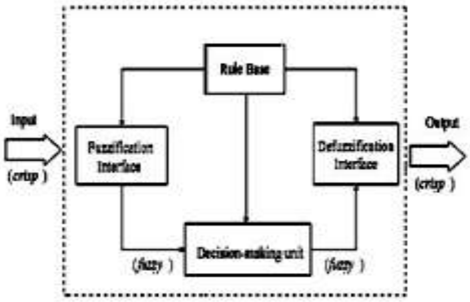


**Figure 4: Input and output interface of FLC.**

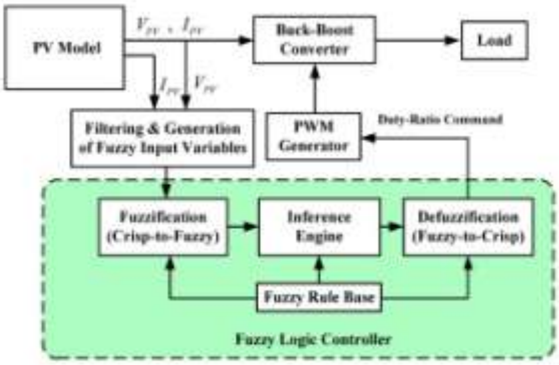


**Figure 5: Fuzzy logic interfacing for PV module.**

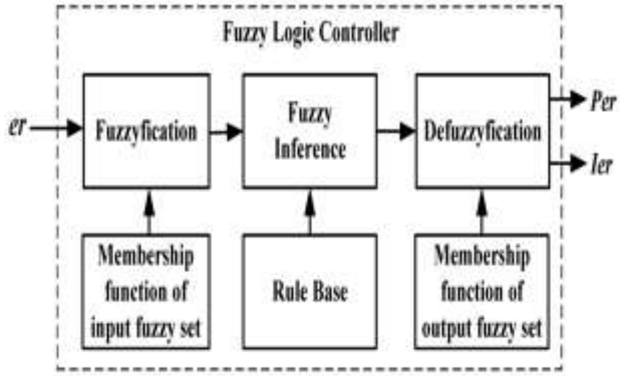


**Figure 7**: Block diagram of Fuzzy Logic Controller.

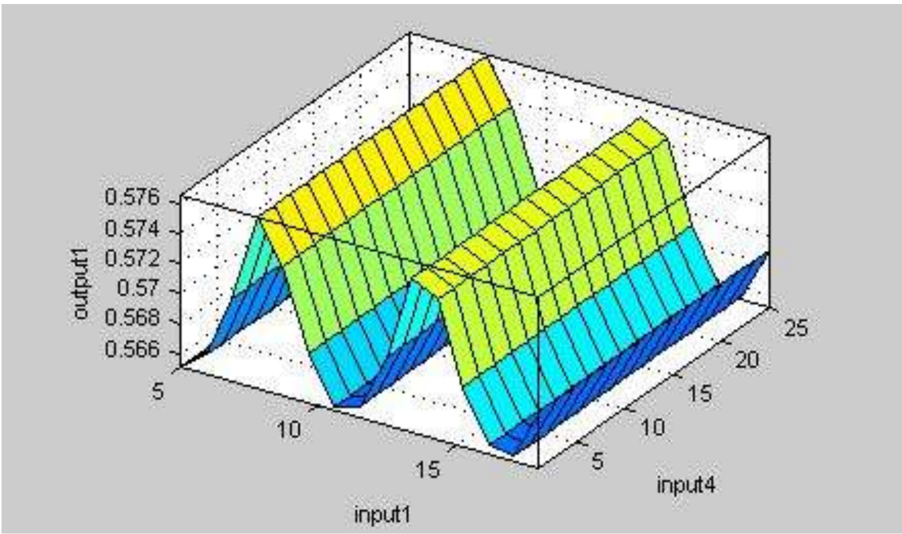


**Figure 5: Fuzzy Logic Input Surface form.**

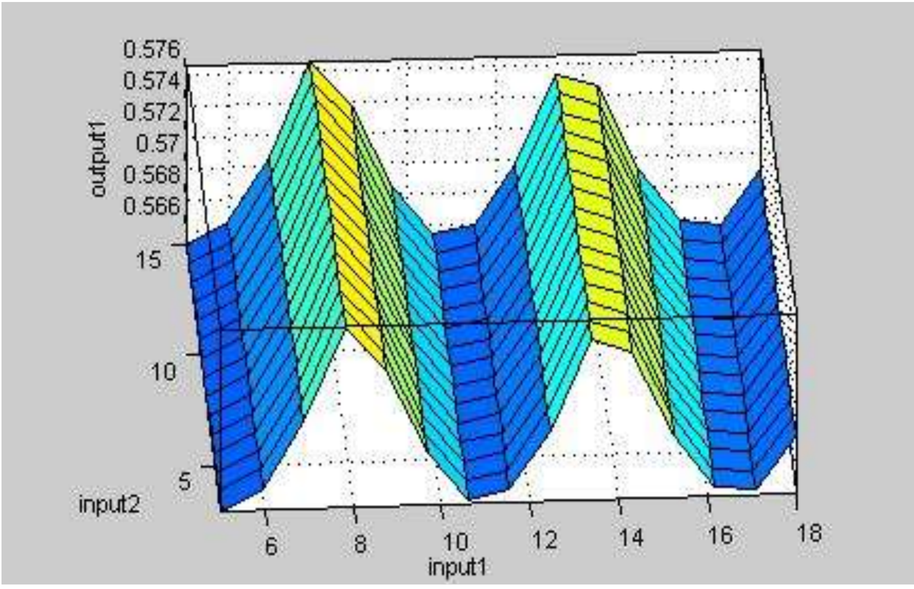


**Figure 6: Fuzzy Logic Output 2.**

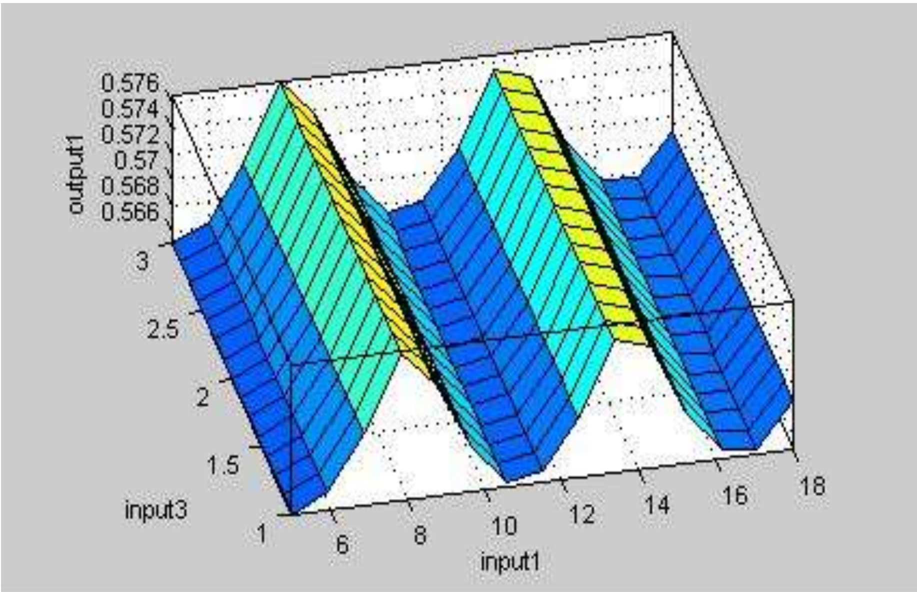


**Figure 7: Fuzzy Logic Output 3.**

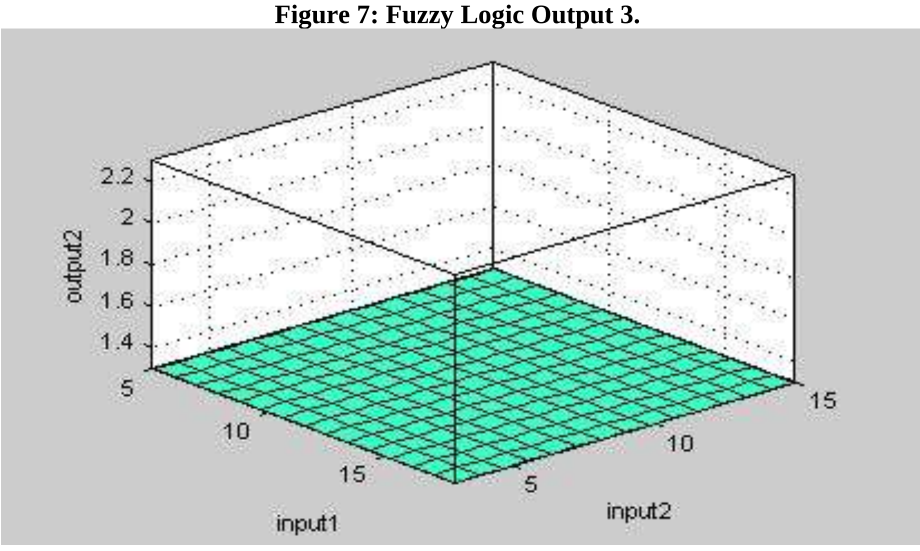


**Figure 8: Fuzzy logic Output 4.**

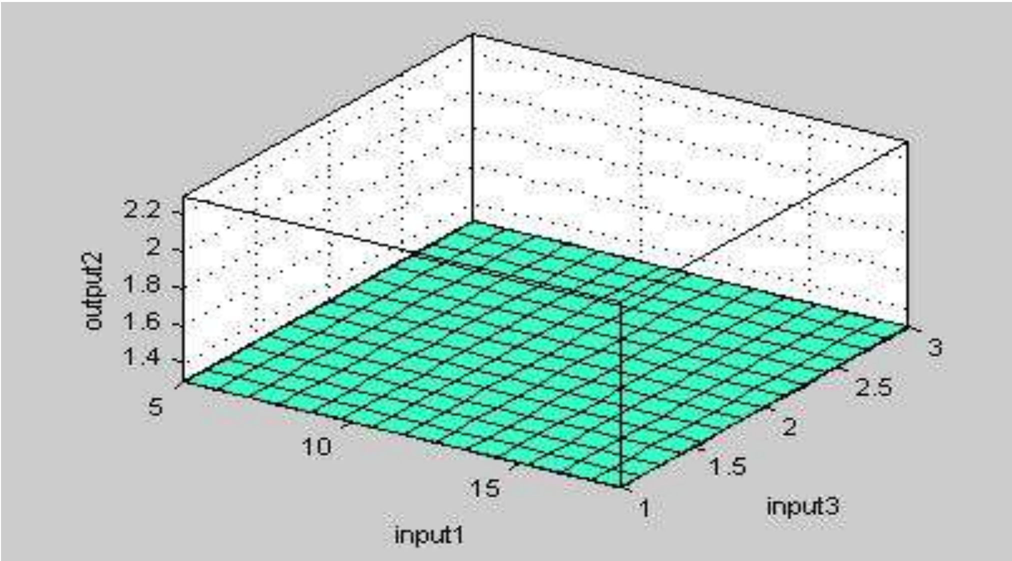


**Figure 9: Fuzzy Logic Output 5.**

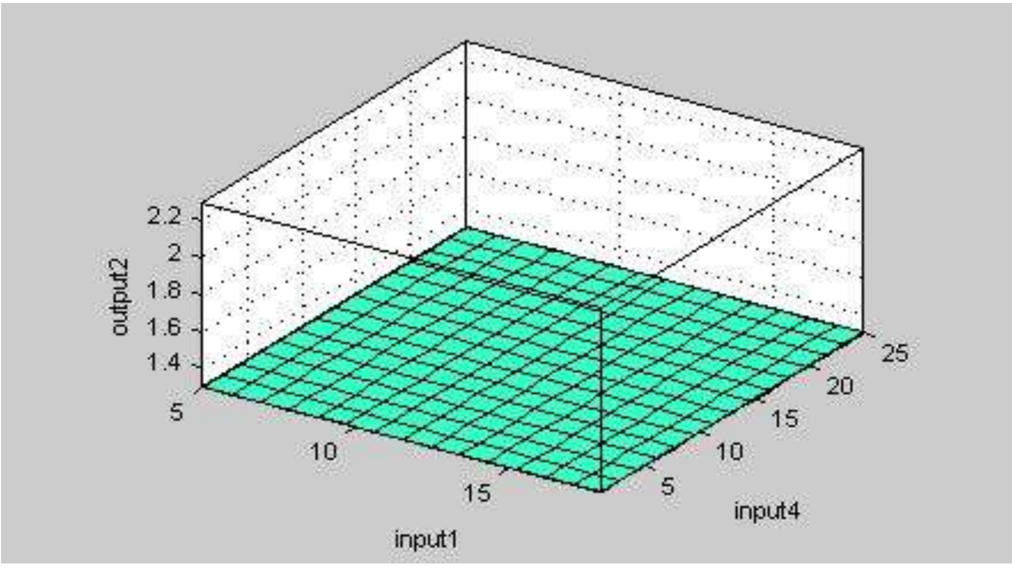


**Figure 10: Fuzzy logic Output.**

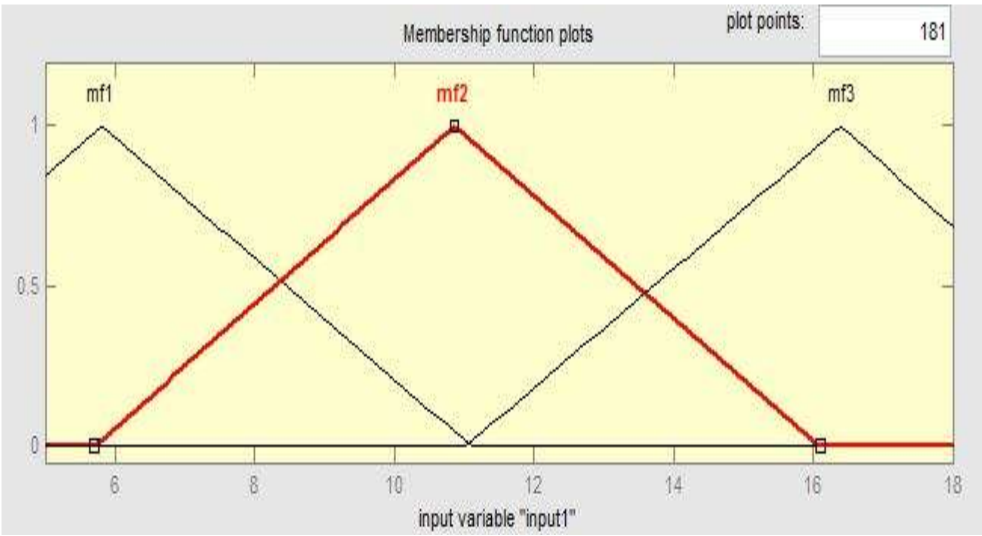


**Figure 11: Membership Function.**

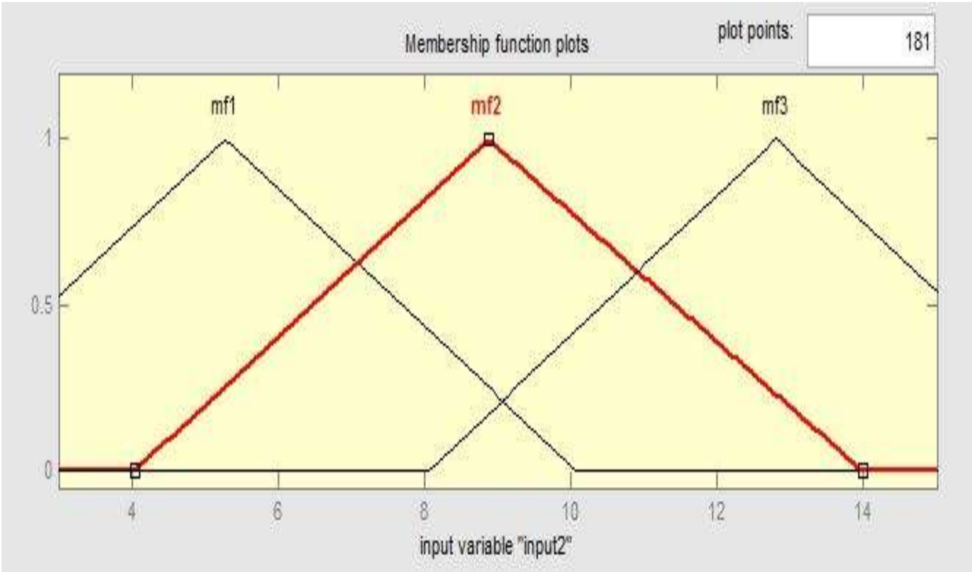


**Figure 12: Membership Function.**

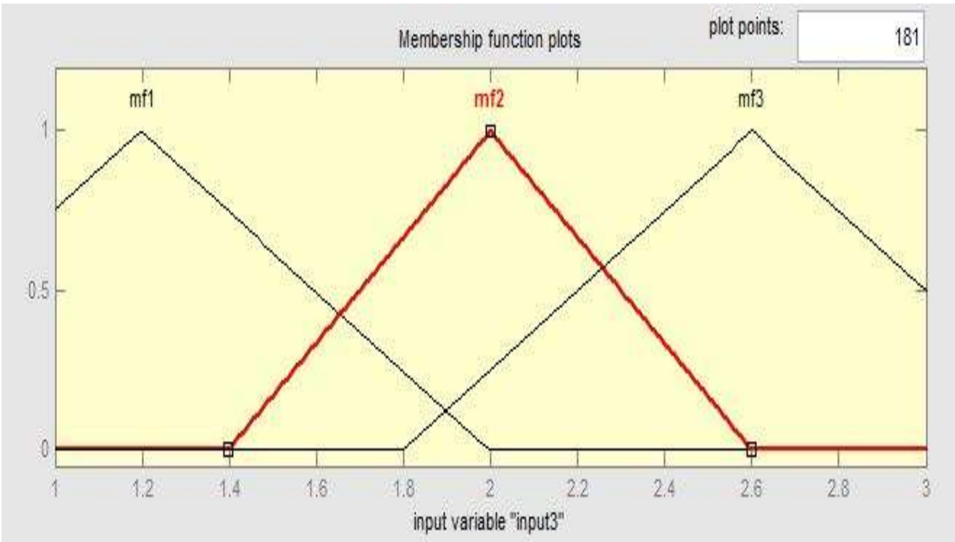


**Figure 13: Membership Function 1.**

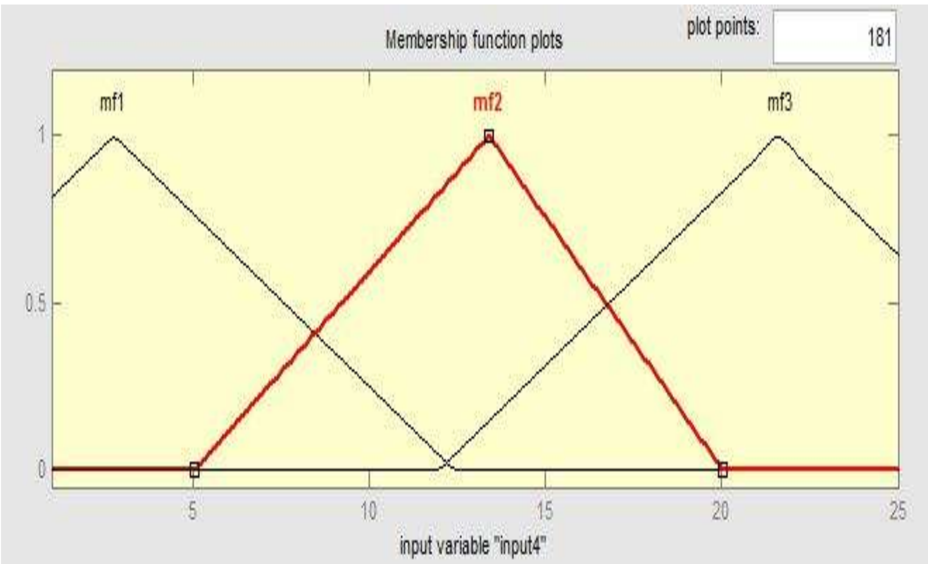


**Figure 14: Membership Function 2.**

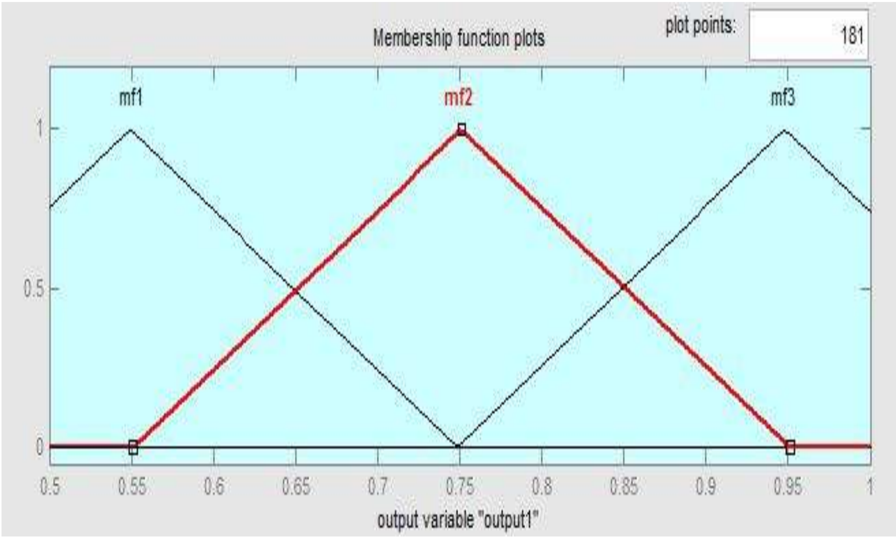


**Figure 15: Membership Function 3.**

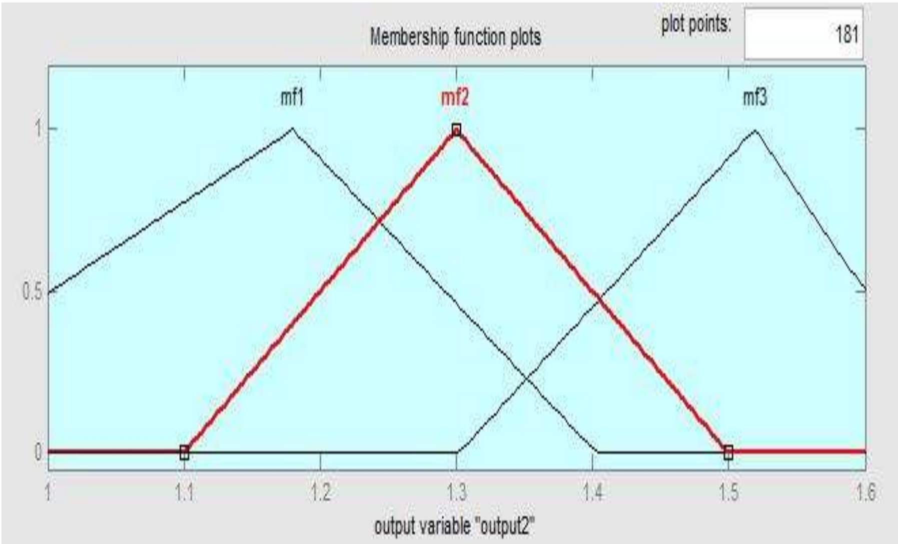


**Figure 16: Membership Function 4.**

In this paper the proposed FLC based Energy Management Controller handles the non conventional energy sources effectively and extends the life time of Battery bank. When the load is low or at initial stages the battery bank supplies load. EEMC produces signal and actuate discharging controller of the battery bank. The charging controller of battery bank is activated depends on the load demand, available resources and battery SOC. In case of high wind speed greater than wind mill rating then it is turned off.

Fuzzy logic controller analyses the individual source power and load demand then controls the selector switch individually. In this paper Mamdani type of fuzzy is proposed with Min-Max method of fuzzification and centroid method of defuzzification. It has 5 inputs named as Pl, Ps, Pw, $P_b$ and $P_{db}$. It has 7 outputs such as SSW1, SSW2, SSW3, SSW4, SSW5, SSW6 and SSW7. All input has 4 triangular membership functions such as Very Low, Low, Medium and High (VL, L, M and H). 13.Maximum possible combination of sources under various loads is formed as rules.

## IV. SIMULATION RESULTS AND DISCUSSION

Simulation model of IPS with energy management controller is developed using MATLAB/ Simulink R2011b. Rating of the IPS is given below

Wind power plant: 4.5 kW,

Solar power plant : 3.5 kW
Battery : 3.5 kW

| | |
|---|---|
| Diesel Generator | : 12 kW |
| Load (DC) | : 1.5 kW, -48 V |
| Load (AC) | : 1.5 kW, 440 V, 50Hz, 3 Phase |

Since telecom tower equipments works in -48V DC the proposed system is designed with the 48V DC bus. Also three phase AC is provided for other usage like light loads , Air Conditioner, & Cooling fan etc., used in telecom station.

## V. CONCLUSION

The wind and sunlight based crossover power framework is mimicked utilizing MATLAB. Fluffy Rationale MPPT Control is connected for wind and sunlight based sources make the framework effective. Half and half power framework supplies air conditioning and DC stack so it is suitable for all applications like remote ranges, towns and slope stations. Fluffy rationale based Viable Vitality Administration Controller controls half and half power framework to give continuous force, minimizing use of diesel, compelling usage of sources and enhances life time of battery. Since the use of diesel generator is minimized outflow of hurtful gasses from it is minimized. So it is a contamination free efficient power vitality framework appropriate to any area and any nation. This proposed framework is ideally suitable for Telecom application where consistent voltage and nonstop power is required.

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