# RURAL HOME ENERGY MANAGEMENT BY SOFT COMPUTING FUZZY CONTROL MODELS FOR A PHOTOVOLTAIC SYSTEM IN INDIA

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**ABSTRACT**

This paper presents control strategies for a PV- DG hybrid energy system for a remote village in Jharkhand, a state in India. The hybrid system designed for rural home with a combination of DG and PV consists of PV module, diesel generator, bidirectional inverter and energy storage battery device. A knowledge based soft computing Fuzzy control technique has been used as a tool to manage the 1kW load power sharing between PV and DG sources and optimize the cost of electricity against maximum household loads of 3600Wh/day. The objective is to run or draw power from the diesel fueled-engine generator for a short period of time to achieve the optimum point of operation and thus reducing the cost of the electricity. The simulation results indicate that the fuzzy control technique can perform well with a hybrid energy system proposed in this scheme for remotely located area studied.

**Keywords:** *Hybrid power system; Photovoltaic; Diesel generator; Fuzzy control.*

## 1. INTRODUCTION

Hybrid power systems as proposed in this study integrate renewable solar energy technologies with diesel generators, to provide electrical power. They are gaining more popularity by the rural masses due to its many feature like free fuel , i.e. sun radiation , that too abundant in nature , straightforward technology etc and is becoming the most commonly used systems for rural electrification especially in remote sector where access to electrical network is not possible or difficult due to various technical and economic reasons. Electricity obtained from this hybrid system is more reliable and more cost effective when compared to the PV system alone or the diesel system alone. The effort have been made in the past by many authors to supplement DG power by other sources [1 2 3]. In order to reduce the cost of electrical supply, investigation has been carried out to integrate the conventional DG source with a standalone PV power and develop a control strategy which can minimize the operational hour of DG consuming costly diesel fuel. This paper presents an approach for program realization on managing the hybrid energy system with minimum operational time of DG using one of the soft computing tools based on fuzzy control technique. The hybrid energy system is modeled to achieve the optimal control variables for getting the electricity at comparatively less economic price.

## 2. ADOPTED AREA OF CASE STUDIED

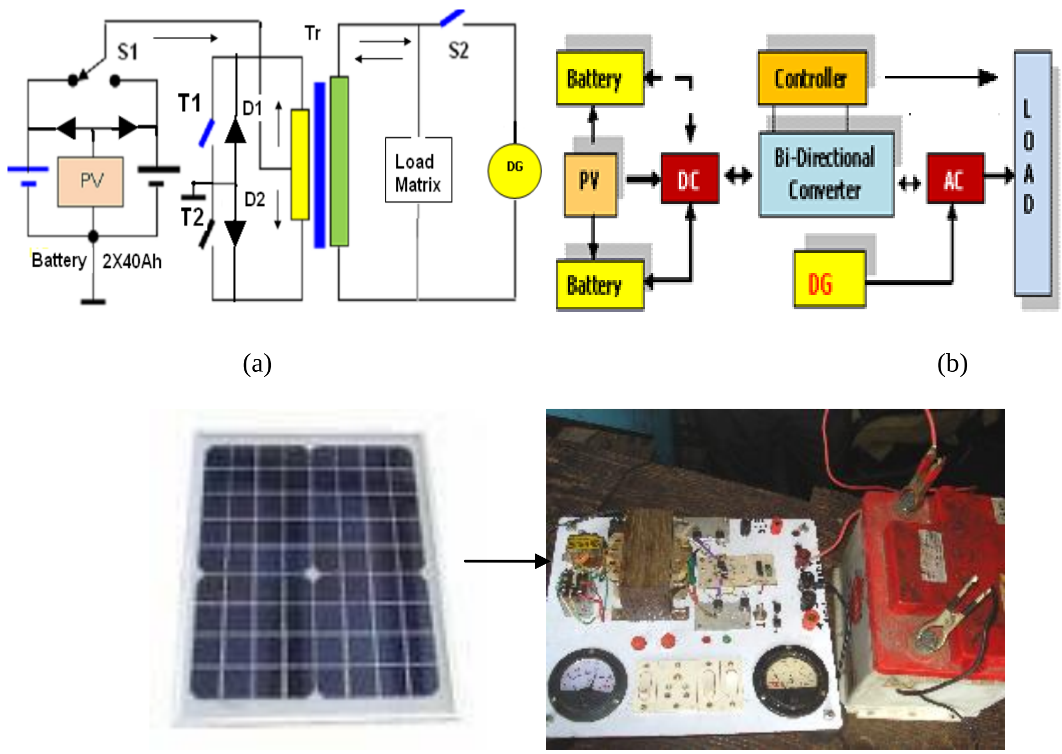
Badam is a village located in remote place in the district of East Singh-bhum of Jharkhand State (India) having an approximate population of 200, where main occupation is daily rated agriculture contractual labour. Although the village is having electric poles but there is no electricity in their homes at present, most of villagers share electricity with community owned 5KVA diesel fueled-engine generators in their homes to run appliances/lighting system or store energy in batteries for later use. Surveys showed that in this area almost every home needs a maximum load of approximate 3.6 kWh/day.

Environmental problems are the biggest problem which arise from these diesel generators and become the source of noise and air pollution. To provide the villagers with 7x 24 hours supply of electricity and reduce the environmental problems, a standalone PV based energy system integrated with conventional diesel generator has been proposed. The electricity generated by PV system use sun radiation as a fuel which is not only freely available throughout the year in the village under study but generates green electricity without noise or air pollution. Although PV system alone can meet most of the energy demand but cannot meet the entire need of energy demand of a house due to high investment cost and lacks in stability for distributing electricity. To provide a continuous form of power generation, a hybrid system is the only viable option as proposed and use of diesel generator as a backup/ standby unit with its minimal operation can reduce the electricity cost as well as cause less impact of environmental problem on the life of villagers. PV energy plays a role of distributed primary energy source which meet almost all the basic load requirement of a house. A diesel generator is the supported/supplementary energy source to generate energy during peak load hours of a day only.

## 3. SYSTEM CONFIGURATION AND OPERATION

The solar (PV) - DG home power system designed [4] is comprising of the following module (Figure 1(a)):

- PV module
- Battery
- Bi-directional Power Converter
- Controller unit
- DG set as a standby power supply source




(a) (b)

( c) (d)

Figure1. (a) Block schematic of a solar power converter with a standby DG Set
(b) Power circuit Model (c) PV Module (d) Prototype system module

The primary source of power supply to rural houses is the PV power. Load power is managed either by PV system or stand by alternative DG source. The power converter unit of the PV system takes the low 12V DC voltage input from PV energy source, stored in battery bank, as shown in Figure 1(b) and convert it into usable 220VAC, 50 Hz 750VA output with the help of a transistorized centre tapped transformer (Tr) based push-pull configured BJT/MOSFET bi- directional converter (inverter) circuit (Figure 1(c & d)). The controller circuit generates PWM square wave pulses, using IC CD 4047 based 50Hz oscillator, to activate and switch on IRF540 MOSFET/2N3055 transistors T1 and T2 alternatively producing AC voltage across the load. DG set is connected to load only when the battery reaches a discharge level of 10.4V and remain on till battery become fully /sufficiently recharged at a level in the range of 12.8V to 13.4V. The intelligent, adaptive control action of the controller performs load power and energy management and thus monitor and manage to deliver continuous power to load. The charging operation is performed by PV source and /or DG source through converter circuit comprising of diodes D1 and D2 while transistor T1 and T2 remain off. The dual charging technique incorporated in the system prevents the battery to go into deep discharging and thus battery never allows attaining a cutoff voltage of 10.4V.

A prototype PV system module has been developed and installed to meet the load energy requirement of one of the rural house of the tribal village of Patamada block located in the outskirt remote area of Jamshedpur city (India):

| | | |
|---|---|---|
| Load Energy | = | 1800 - 3600 watt-hours over a period of 24 hour, computed over a period of a month |
| PV size | = | 2 X 75 Wp, 12 V |
| Battery Size | = | 2x Dual 40Ah , 12 V low self discharge inverter grade tubular lead acid battery |
| Load(s) | = | CFL lamps , Fans, TV and Rural Industrial/household equipment including pump etc |
| Converter | = | 750 VA, 12VDC ~ 220 V SPWM AC, 50Hz |
| Mobility | = | Portable |

## 4. LOAD POWER CONTROL STRATEGIES PLANNING

The control strategy for a hybrid power system is a control algorithm for the interaction among various system components. The system controller determines the starting or stopping of the diesel generator, charging battery operation, and cutting-in or cutting-out of the renewable energy sources. Determining the best condition of operation is the key to achieve optimum operation. Figure 2 shows the power flow diagram of the system with input and output control parameters. The inputs of the controller are the parameters of site unpredictable load power, renewable varying output power stored in battery, where as output parameter is the switching on diesel generator and converter for load and charging operations respectively. A power control strategy is also needed to control the flow of power and to maintain adequate reserves of energy in the battery storage devices. The fuzzy based technique/ algorithm [5,6] has been implemented in the control strategy to achieve optimal operation of DG resulting in saving on cost of electricity .

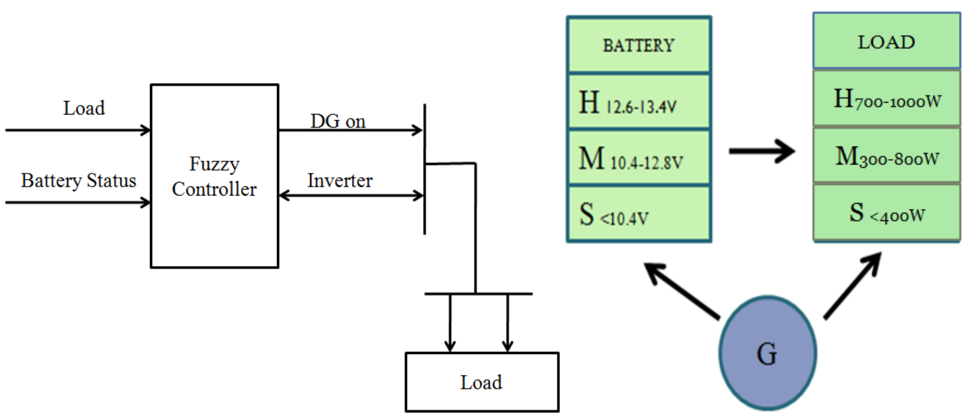



Figure 2.(a) Schematic diagram of control strategy of PV-DG hybrid energy system (b) Power flow diagram

## 5. FUZZY CONTROL ALGORITHM

Fuzzy logic control has been used as a tool to manage the hybrid energy system. The system is comprised of PV, a diesel generator, bi-directional inverter and energy storage battery device. The procedure in making the control designs are setting the constraints, assign the linguistic variables and setting the rules for the controller. Solar radiations and load(s) are the areas that affect the studied outputs and hence load demand and the PV energy stored in battery are considered to be the input variables. The output variables of this controller are the turn on time period of the generator and the battery charging period. The objective of the designed controller is to control the turn on time period of the generator and the inverter to work as a load power source or battery charger respectively. Since a photovoltaic hybrid system that includes a diesel generator produces non fuzzy measurements, these had to be changed by fuzzification. Equation (1) is the max-min method of fuzzification and is used to set the rules of the controller.

$$\mu = (\alpha_1 \wedge \mu_1) \vee (\alpha_2 \wedge \mu_2) \quad (1)$$

Similarly, since the hybrid energy system cannot respond directly to the fuzzy controls, the fuzzy control sets generated by the fuzzy algorithm have to be changed back by using the method of defuzzification. Subsequently, the approximate centre of gravity (COG) method as shown in equation (2) is used for the defuzzification.

$$COG = \frac{\sum_{i=1}^{n} \mu_i \mu(i)}{\sum_{i=1}^{n} \mu(i)} \quad (2)$$

***Input Variable***

**Load:** Small : trim f (0 0 40)
Medium : trim f (30 50 80)
High :trim f (70 90 100)

**Battery status:** Small : trim f (0 0 40)
Medium : trim f (30 50 80)
High : trim f (70 90 100)

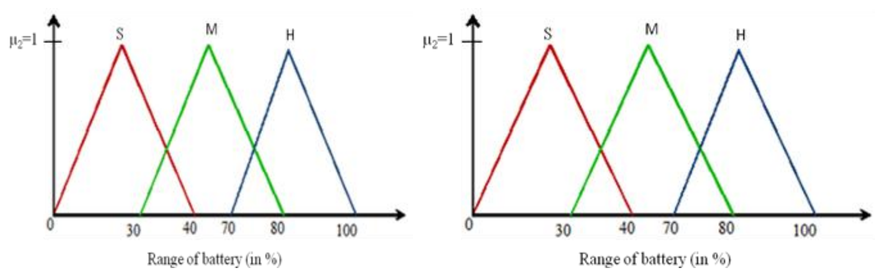



Figure 3.(a) Load Membership function (b) Battery Membership function

Figure 3 (a) and (b) represents the membership functions, which represent the status of load and battery respectively.

***Output variable:***

**DG System:** DG on trim f (100)
DG off trim f (0)

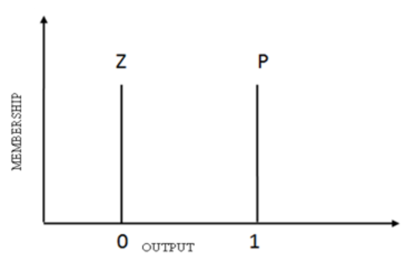



Figure 4. Fuzzification of the output
DG On (P=1) DG Off(Z=0)

## 6. SIMULATION RESULT

Knowledge based decisions, based on the input conditions of battery as well as load, have been formulated and shown in Table1. The output result i.e. P or Z activate the DG to switch it ON or OFF respectively.

Table (1): Fuzzy Rule

| Load / Battery | Low | Medium | High |
|---|---|---|---|
| Low | Z | Z | Z |
| Medium | P | P | Z |
| High | P | P | P |

The simulated results obtained for a typical day are shown in Figure 5. The result is based on the time periods for the use of diesel generator. Here's some rule that explains the working principle of our system based on the fuzzy, it is represented as follows:

1. If (L is S) and (B is S) then O = Z
2. If (L is S) and (B is M) then O = P
3. If (L is S) and (B is H) then O = P
4. If (L is M) and (B is S) then O = Z
5. If (L is M) and (B is M) then O = P
6. If (L is M) and (B is H) then O = P
7. If (L is H) and (B is S) then O = Z
8. If (L is H) and (B is M) then O = P
9. If (L is H) and (B is H) then O = P

The meanings of the labels designating the names of linguistic values are:

L: load, B: battery, S: small, M: medium, H: high, O: action, Z: zero, P: positive.

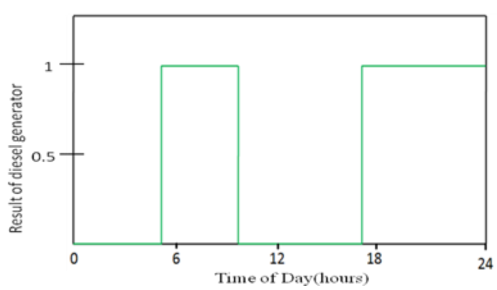



Figure 5. Simulation result of diesel generator for the load requirement of a typical day (saving = 50%)

## 7. LOAD SENSITIVITY ANALYSIS

The load sensitivity analysis has been carried out to study restoration time under Off condition of DG (i.e. Gen Power $P_G$= 0). The variation of load(s) with the changes of input parameters and disturbances are governed by the following equations**:**

Load(s) Power ($P_L$) = PV power $P_{PV} \pm$ Battery Power $P_{BAT} \pm$ Load Disturbances (3)

The sensitivity analysis for the load variation with the changes of input parameters has been tabulated in table (3).

Table (3): Sensitivity analysis of PV system in absence of DG power support (Presence = 1, Absence = 0)

| $P_{PV}$ | $P_{BAT}$ | Load Disturbances | Deviation % | Restoration Time (Second(s)) |
|---|---|---|---|---|
| 0 | 1 | 1 | $\pm$10 | < 1s |
| 1 | 0 | 1 | $\pm$10 | < 1s |
| 1 | 1 | 1 | $\pm$10 | <1s |

## 8. LIFE CYCLE COST ANALYSIS (3 YEARS)

The life cycle cost (LCC) analysis for duration of its service period has been done to investigate the cost effectiveness of the proposed system as depicted in Table 4.

Table (4): Cost effectiveness of system computed over a service period of 3 Years

| System | | Rating | Cost of System+ Fuel cost / Rental Charges* | Total value (INR) |
|---|---|---|---|---|
| PV System | Standalone | 2X750VA | Rs 1,00,000 | Rs 1,00,000 |
| Generator | Standalone | 1kW (Stand alone Gen) | Rs 35,000 + Rs 50,000 | Rs 85,000 |
| PV System + Generator | Hybrid | 750VA+1 kW(5 KVA Gen) | Rs 50,000 + Rs 25,000* | Rs 75,000 |

## 9. CONCLUSION

DG system and its integration with PV system including control strategy planning using soft computing fuzzy tool have been studied. The fuel consumption of the diesel generator is one of the main components of the total operation cost over its lifetime. Therefore, determining the optimum interval time for starting and stopping the diesel generator with respect to the load profile is a main factor for limiting diesel fuel use. The simulated results show that introducing a fuzzy logic controller optimizes the running time of DG and has resulted in less consumption of fuel thus reducing the cost of electricity and also reduces pollution. The saving can go up to 50-100%.

Solar (PV) - grid hybrid system has a great potential in future as one of renewable energy technologies which can meet the energy demand of rural sectors. The hybrid technology, integrating PV with DG/grid, offers solution to local power generation in terms of providing uninterrupted reliable qualitative and high efficient supply without /with minimum use of standby DG at an effective cost. The easy installation and maintenance free operational feature of the PV system has gained more popularity among the rural masses. The successful implementation of system has following outcomes:

- Generating green electricity and meeting increasing load(s) demand of a rural house with minimum use of DG sets as well as preserving the nature.
- Minimum use of DG set reducing the maintenance and operation cost of the system
- Cost Effective i.e. the minimum running hours also reduces the maintenance cost of a diesel generator

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