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Off-grid electrical power generation and environmental impact with renewable energy in India

Bharat Modi* and Umesh Kumar Rathod**

India is developing country and electricity demand is increase day by day. Many of Indian villages about 18000 are not electrified since independence. Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) is a government of India scheme designed to provide continuous power supply to off-grid rural India. The purpose of this paper is to propose the best hybrid technology combination for off-grid electrification of rural area where conventional grid power supply is not possible. Electricity need for an off-grid remote area supply from a mixture of biodiesel generator, small hydro plant and renewable energy resources to satisfy in a reliable manner. Here we are using HOMER^{TM} (Hybrid Optimization of Multiple Energy Resources) software is used for whole analysis. The simulation results indicate that the proposed hybrid system would be a feasible solution for distributed generation of electric power for remote locations compare to conventional grid extension.

Keyword: *DDUGJY, HOMER^{TM}, Hybrid System.*

1.0 INTRODUCTION

The electrical energy demand increase day by day. In all over world about 1.3 billion people in the world (or about 1 in 5) without access to electricity in 2010 [1]. The challenge of providing reliable and cost-effective services remains one of the major global challenges. The grid extension still remains the preferred mode of rural electrification [2]. The grid extension of the central electricity grid to geographically remote and sparsely populated rural areas can either be financially unviable or practically infeasible. Off-grid options can be helpful in such cases. The purpose of this research work is to find the best combination of renewable energy source from the available resources in a given remote area location to reduced grid extension. We can also find out that such a hybrid option is a cost effective solution or not. The Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme will enable to initiate much awaited reforms in the rural areas of India. It focuses on feeder separation (rural domestic& agricultural) and strengthening of sub-transmission & distribution infrastructure including metering at all levels in rural areas.[3].

113 villages yet to be electrified Out of 43,264 census villages, 43,151 villages (99.7%) have been electrified in Rajasthan, India [4]. All remaining off-gridvillage are electrified under DDUGJY. In our research work we selected remote are anarayanpura village of district Jhalawar, Rajasthan for electrification. First, we identify the available resources, model electricity generation based on multiple combinations of renewable energy source. Secondly, we used HOMER software and obtain the best Simulink result of hybrid power systemon the basis of cost of electricity generation. Another advantage using

*Reader, Electrical engineering department, SKIT, Jaipur-302017, bharatalone@gmail.com,9462884862
**M.Tech scholar, Power system, SKIT, Jaipur-302017, umeshrathod.research@gmail.com

of Renewable energy sources in hybrid power system, the total CO_2 emission is reduced comes from gird-extension.

2.0 LITERATURE REVIEW

The aim of the literature review presented here is two-fold: first, this provides evidence of knowledge gap that justifies the need for this work and second, it also provides support for the methodology used in the study and is a source of information for comparison, triangulation and referencing.

For developing countries, a large number of studies exist and a detailed review of this literature is beyond the scope of this paper. Instead we focus on a selected set for our purpose. Givler and Lilienthal [5] conducted a case study of Sri Lanka where they identified when a PV/ diesel hybrid becomes cost effective compared to a stand-alone small solar home systems (50 W PV with battery). This study considers an individual household base load of 5 W with a peak of 40 W, leading to a daily load average of 305 watt-hours. Through a large number of simulations, the study found that the PV-diesel hybrid becomes cost effective as the demand increases. However, this study focuses on the basic needs as such and does not include productive use of energy. Munuswamy *et al.* [6] compared the cost of electricity from fuel cell-based electricity generation against the cost of supply from the grid for a rural health Centre in India, applying HOMER simulations. The results showed beyond a distance of 44 km from the grid, the cost of supply from an off-grid source is cheaper. This work just considered the demand of a rural health Centre and was not part of any traditional rural electrification programed. Hafez and Bhattacharya [7] analyzed the optimal design and planning of renewable energy-based micro-grid system for a hypothetical rural community. Where the base load is 600 kW and the peak load is 1183 kW, with a daily energy requirement of 5000 kWh/day. The study considers solar, wind, hydro and diesel resources for electricity generation. Although the study considers electricity demand over 24 hours, the purely hypothetical nature of the assumptions make the work unrealistic for many off-grid areas of developing countries. Lau et al. [8] analyzed the case of a remote residential area in Malaysia and used HOMER to analyses the economic viability of a hybrid system. The study uses a hypothetical case of 40 households with a peak demand of 2 kW. The peak demand is 80 kW and the base demand of around 30 kW is considered in the analysis. Although such high rural demand can be typical for Malaysian conditions, it is certainly not true for others. The study also does not consider any productive use of electricity.

It can be seen that the hybrid options have often considered a limited set of technologies. Moreover, most studies concentrate on supplying electricity merely for domestic purposes and do not take into account the electricity demand for agricultural, irrigations, community purposes and for small scale business units for the socio-economic development of the whole region. The load profiles are also not carefully considered in many cases. These issues are considered in the present study, thereby bridging the knowledge gap.

3.0 METHODOLOGY

3.1 HOMER^{TM} Software

The HOMER software developed by National Renewable Energy Laboratory (NREL) for designing hybrid power systems but complements it by undertaking HOMER analyses. This is indicated in Figure 1.

The developers of the HOMER model have provided a detailed description of the HOMER model in "Integration of Alternative Sources of Energy" [9] and "Computer Modeling of Renewable Power Systems"[10].

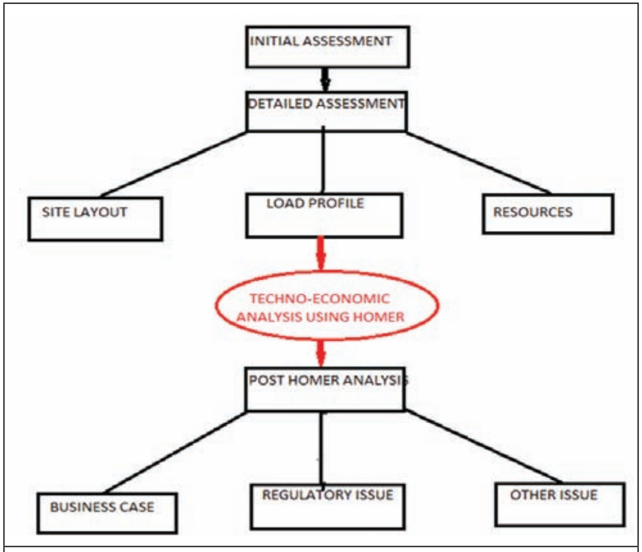

FIG. 1. FRAMEWORK OF ANALYSIS

In the HOMER™ analysis, a detailed assessment of the remote area load, site layout and available resources in the selected remote area is conducted. This is carried out outside HOMER and data is fed into the software. In the HOMER analysis the hybrid system is designed, followed by a techno-economic analysis. It compares a wide range of equipment with different constraints and sensitivities to optimize the system design. The analysis is based on the technical properties of the system and the life-cycle cost (LCC) of the system. The LCC comprises of the initial capital cost, cost of installation and operation costs over the system's life span. HOMER performs simulations to satisfy the given demand using alternative technology options and resource availability. Based on the simulation results, the best suited configuration is selected [11].

We have considered a combination of the following technologies biodiesel generator, small hydro plant; wind turbine, solar PV cell array systems and batteries for back-up (see Figure 2 for a schematic system configuration diagram). In the hybrid system the bio-diesel generator, small hydro power plant,wind turbine is AC-coupled on AC side of the network and the solar PV cell array and the batteries are connected to its DC side.

In our research, renewable energy source making the whole system a sustainable, clean and carbon neutral system. Renewable energy sources not only for the purpose of electricity generation but also for working effectively towards green-house gases emissions mitigation by not burning fossil fuels.

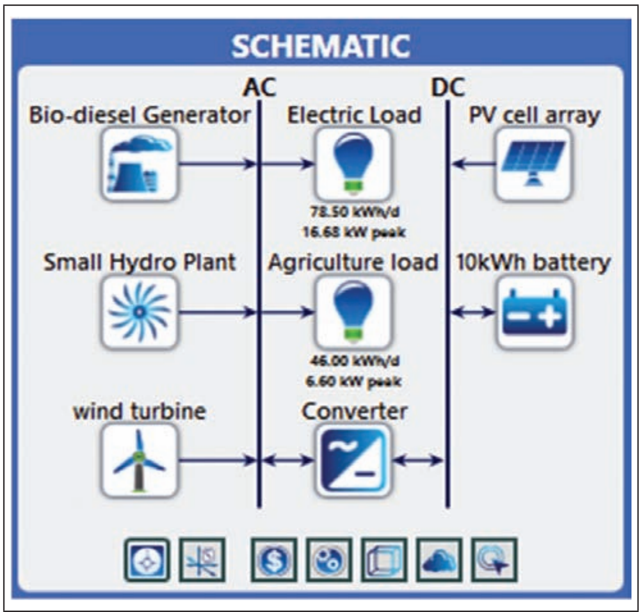

FIG. 2. SCHEMATIC SYSTEM CONFIGURATION

3.2 System Modeling

In our research we choose off-grid Narayanpura village is located in Jhalrapatan Tehsil of Jhalawar district in Rajasthan, India. It is situated 23 km away from sub-district headquarter Jhalrapatan and 15 km away from district headquarter Jhalawar [12]. First, wepick out best hybrid system from available renewable sources and Second, remote area electrified by hybrid system.

3.2.1 *Load Assessment*

In a remote rural village the demand for electricity is not high compared to urban areas. Electricity is demand divided into two parts

- Domestic use (for appliances like radio, compact fluorescent lamps, ceiling fans, and table fans etc.)
- Agricultural activities (such as water pumping).

In our research, the village energy requirement is carefully estimated considering existing load profile data available in state government records. We have also consulted previously published literature on Indian villages and triangulated with expert opinions and personal judgments.

3.2.2 *Domestic Use*

The demand has been estimated separately for two distinct seasons prevailing in this area, namely summer (April to October) and winter (November to March) considering the appliance holding and use patterns for households [10] show in below Table 1:

TABLE 1

ESTIMATED ELECTRICITY DEMAND FOR OFF-GRID REMOTE AREA

Domestic purpose	Number in use	Power (W)	Demand in summer season		Demand in winter season	
			h/day	Wh/day	h/day	Wh/day
Low energy (CFL)	3	20	6	120	7	140
Ceiling fan	1	50	15	750	0	0
Total				870		140
No. of houses	78			63,960		10,920
Shops	10	600	8	4800	7	4200
School	1			1360		1200
Community Centre	1	1000	8	8000	6	6000
Total		1670		78,120		22,320

3.2.3 *Agriculture Activities*

The total agriculture and irrigation load for village 63 kWh/day.

The energy E in watt-hour/day (Wh/day) is equal to the power P in watts (W), times the time period t in hours (h) in per day:

$$E = P(W) \times t(h/day) \qquad \ldots(1)$$

$$=1500\ W \times 6\ hours/day$$

$$=9000 Wh/day$$

For seven unit of electric pump the total Energy will be

$$E = 7 \times 9000\ Wh/day$$

$$E = 63000\ Wh/day$$

$$E = 63\ kWh/day$$

3.3 Resource Assessment

We have considered solar, wind and biodiesel generator resources in this simulation. The solar resource and wind turbine used for remote area at a location of unusable land near to SSTPS. The monthly average temperature and wind resource data from an average of ten years was taken from the above NASA resource website based on the longitude and latitude of the remote area location [13].

In this analysis, bio-diesel generator, small hydro plant, solar PV cell array and wind turbines are the intermittent resources and the battery is kept for backup. Batteries and converter are for storing, converting electricity respectively. The grid connection in this study is only used as a comparison for the analysis and determination of the economic distance to grid.

4.0 ECONOMICAL MODELING

Our aims to minimize the total net present cost both in finding the optimal system configuration and in operating the system. All economic calculations are in constant rupees terms.

The project's lifetime is considered to be 25 years with an annual discount rate of 10%. The system fixed capital cost and the system fixed O&M cost is show in given below Table 2. The system fixed capital costs include various civil constructions, logistics, labor wages, required licenses, administration and government approvals and other miscellaneous costs.

TABLE 2

SYSTEM VARIOUS COST IN RS. LAKHS

Component	Capital	Replacement	O&M	Fuel	Salvage	Total
Flat pv cell arry	143.98	00	0.035	00	00	144.01
Wind turbine	104.00	22.97	2.11	00	11.81	117.27
Hydro	29.25	00	3.16	00	00	32.41
Bio-diesel generator	73.12	187.78	13.14	33.53	0.88	306.70
10kWh battery lead acid	0.55	0.38	0.007	00	0.042	0.90
Converter	93.60	30.15	0.042	00	4.72	119.07
System	444.50	241.30	18.49	33.53	17.46	720.37

5.0 RESULTS AND DISCUSSION

This section presents the results of our analysis. First, the Optimization results by simulation are presented. Second, the emission reduction is calculated. Hybrid power system components for our case study show in below Table 3 system architecture

TABLE 3

SOURCES AND THEIR CAPACITY FOR SYSTEM ARCHITECTURE

Source	Capacity
Bio-diesel generator	15 Kw
PV cell array	10 kW
Wind turbine	10 kWx2unit = 20 kW
System converter	20 kW
Battery	10 kWhx1 unit = 10 kWh (cycle charging)
Small hydro power plant	4.7088 kW

The total electricity generation by hybrid systems 85,082.00 kWh/y and total demand 45,438.00 kWh/y. The excess electricity 25,344.00 kWh/y of electricity which is 35.6% of total electricity generated goes unused due to low demand and is fed to dump loads. In a particularly high in summer month, shows that this system has the capability in meeting the demand growth in the future. The contribution of renewable energy sources in hybrid system show in below Table 4. The solar PV cell array plants, bio-diesel generator plant, wind turbine plant and hydro power plant contribute 23.97%, 24.35%,5.84% and 45.84% respectively to electricity generation.

TABLE 4

ELECTRICITY GENERATION BY DIFFERENT SOURCES

Source	kWh/y	Percentage (%)
Flat PV cell array	17,067	23.97
Biodiesel generator	17,338	24.35
Wind turbine	4,155	5.84
Hydro	32,630	45.84
Total	71,189	100.00

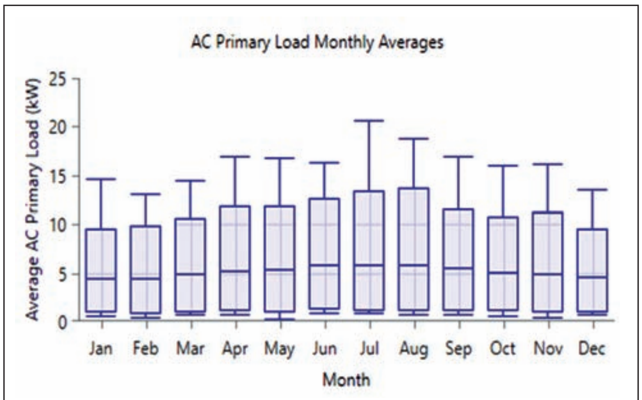

FIG. 3. AVG. AC PRIMARY LOAD IN VARIOUS MONTH

The avg. ac primary load various in month and the monthly distribution of the electricity produced in kW by the wind turbine, PV cell array, biodiesel generator and hydro power plant show in respectively below Figure 4 and 5. From January to December, the biodiesel generator is mostly used combined with PV cell array and peak load in peak month is met by wind turbine.

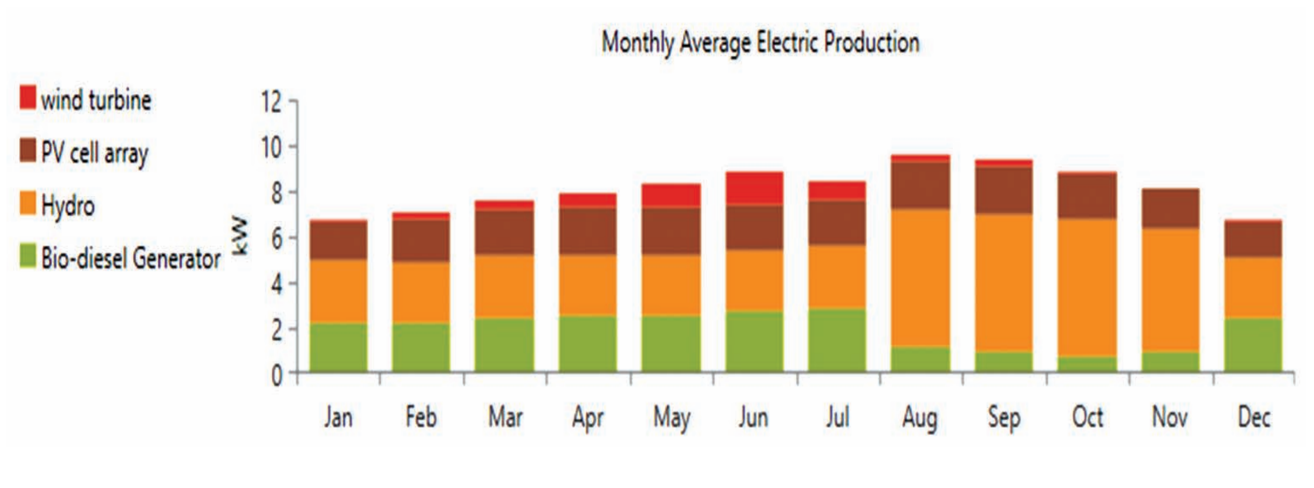

FIG. 4. MONTHLY AVERAGE ELECTRIC PRODUCTION BY HYBRID SYSTEM

The total Net Present Cost (NPC), levelized cost of electricity and operating cost for hybrid system show in below Table 5. According to optimization result of hybrid system the Levelized Cost Of Electricity (LCOE) for hybrid power system Rs.146.25.

$$\text{LCOE} = \frac{\text{sum of cost over lifetime}}{\text{sum of electricity produced overlifetime}}$$

$$= \sum_{t=1}^{n} \frac{It+Mt+Ft}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{Et}{(1+r)^t} \quad \ldots(2)$$

Where

I_t = investment expenditure in the year t

M_t = O&M expenditure in the year t

F_t = fuel expenditure in the year t

E_t = electricity energy generated in the year t

r = discount rate

n = expected lifetime of system or power station.

So, that the per unitcost of electricity (COE)

$$= \frac{146.25(in\ rupees)}{49.71088(in\ kWh)} = 2.942 \text{ rupee/kWh}$$

COE for hybrid system Rs. 2.942 rupee/kW his cheaper than the cost of electricity Rs. 4.615 rupee/kWh for 250 MW single unite of suratgarh super thermal power station, Rajasthan, India based on coal [14]. Therefore grid extension does not appear to be a viable option to meet the village load.

TABLE 5

TOTAL NPC, LCOE AND OPERATING COST

Name of cost	Cost in rupees
Total NPC	720.37 lacks
Levelized COE	146.25
Operating cost	25.49 lacks

6.0 EMISSIONS

In the environmental impact category, the HOMER™ model evaluates emissions of pollutants such as carbon dioxide, carbon monoxide, unburned hydrocarbon, particulate matter, sulfur dioxide, and nitrogen oxide [15].

The optimal hybrid power system would save 64,920.00 kg/y of CO_2 over one year show in below Table 6. In addition, emission of particulate matters and nitrogen oxides will be reduced due to reliance on renewable energy systems. In hybrid system we used B100 bio fuel for bio-diesel generator.

TABLE 6		
EMISSION REDUCTION		
Quantity	**Value**	**Units**
Carbon dioxide	64290.00	kg/y
Carbon monoxide	158.69	kg/y
Unburned hydrocarbon	17.58	kg/y
Particulate matter	11.58	kg/y
Sulfur dioxide	129.11	kg/y
Nitrogen oxide	1416.00	kg/y

If we electrified off-grid remote area with help of grid extension than cost of transmission is also added i.e. total cost with grid extension is further increase.

Based on the above analysis, it can be concluded that a hybrid system becomes a viable option in an off-grid location in India than grid extension.

6.0 CONCLUSION

Our research for a technically feasible and economically viable hybrid solution for off-grid electricity supply to a remote village resulted in a least-cost combination of wind turbine, solar PV cell array, bio-diesel, small hydro power plants and batteries. Hybrid system can meet the demand in a dependable manner at a cost of Rs 2.942/kWh.

The main lessons from this case study are:

- A combination of technologies improves supply reliability and hence makes better business sense.
- Economically viability is increases along with increase in number of villages.

Results, The Deen Dayal Upadhyaya Gram Jyoti Yojana (DDUGJY) scheme is more efficient and reliable if we electrified off-grid load with mixture of renewable energy sources than conventional grid extension and use of only solar panel.

FUTURE SCOPE

- We can reduce peak demand on the conventional power plant.
- We can proper use all renewable sources available at remote area.
- We can reduce CO_2 by using renewable sources.

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