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# RURAL ELECTRIFICATION USING RENEWABLE ENERGY SOURCES

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**ABSTRACT**

*Rural electrification is one of the main issues in developing country like India due to large number of small villages and remote Islands are unelectrified. Due to financial and technical issues, extension or installation of grid lines with high voltage is not possible in these areas. Main electrical load in these villages is residential load which consist of mostly lighting load. The study presented in this paper shows availability of solar and biogas at villages is sufficient to meet electric demand and can replace use of costlier fuel for electricity. Considering cost data of 2007, 2012 and 2016; economically feasible option is tested for five villages using cost of energy (COE) calculation for solar, biogas and diesel generator (DG). Based on the analysis of cost of energy for the year 2016, size require of solar photovoltaic systems require for these villages is also presented.*

***Keywords: Balance of system (BOS), biogas, and cost of energy, renewable energy sources, and solar photovoltaic.***

## I. INTRODUCTION

In modern world energy has becomes an important utility. It is one of main factor in country's development. Normally there are many forms of energy chemical, thermal, electrical etc. This energy can obtain from the conventional sources like diesel, petrol, coal, LPG and CNG etc. Among all types of energy electrical energy is most favourable due to easy in transfer over long distance and easy in use to consumer.

India is developing country and having world's second largest country in population. Hence electricity consumption is high and will increase in future. The per capita consumption of electricity in India during year 2016 was 768kWh/yr. India is world's third largest producer and fourth largest consumer of electricity [1], [2]. Major consumption of electricity is in industrial sector (44%) and in agricultural sector (18%). To fulfil the demand of electricity as mentioned the majority of power plant in India is coal based (59%). In India mainly coal is used for power generation and being conventional its storage is limited. Its impact on environment results into large amount of carbon dioxide emission. Also demand of imported coal forced to spend more money for generation of electricity. Hence search of another option for source of electricity is very important.

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There are 590000 villages in India and about 700 million people live in rural and remote part of country. Most villages in remote area not get sufficient electricity which slow down the growth of rural India both at social and economic development. Total electricity coverage area 80% and 20% remain unelectrified which consists most of remote area. In India53% of rural population has access of grid electricity and 43% population use conventional sources for electricity [3], [4]. In this remote area the power is mainly provided through diesel based power generation. As the cost of diesel per liter increase day by day the cost of energy using DG is very high not affordable to villagers. The financial problems for remote electrification include high capital cost, lack of subsidies etc. for long transmission of power. The technical problems faced in remote place electrification include severe transmission and distribution losses, voltage drop and unreliable operation in distribution system because of long distance from power stations [5]. Due to these issues the use of renewable energy sources for remote electrification is the best option due to their availability at place of requirement. It also reduces voltage drop and the expenses on long distance transmission line. In this paper sample data [6] of five villages (Bharatpur, Laxmanpur, Ramnagar, Sitapur, and Neil Kendra) of remote Neil Island is adapted for the search of techno economic renewable options. The size of renewable energy source and calculation of cost of energy (COE) are determined for the search of best option for village electrification.

## II. STUDY AREA: NEIL ISLAND

### 2.1 Location of Neil Island

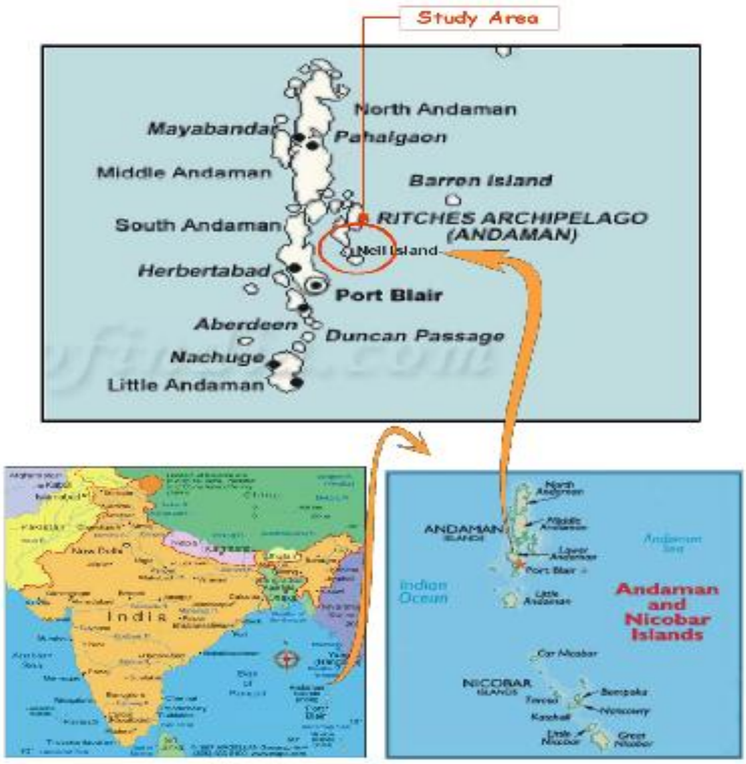


**Fig.1.Location map of Neil Island [6]**

The location map of remote Neil Island is shown inFig.1. It is located between 6° 45́ and 13°41́ North latitudes and 92°12́ and 93°57́ East longitude. The island has an area of 18.9 $Km^2$ and consists of five villages (Bharatpur, Laxmanpur, Ramnagar, Sitapur, and Neil Kendra) [6]

**2.2 Energy scenario at Neil Island:**

The details of connected load [6] of five villages are shown in Table 1. Maximum load found to be during evening time i.e. from 5.30 pm to 11.30 pm and most of load is lighting loads. All five villages electrified through the diesel power generation so the distribution system of electricity present at Neil Island.

## III. CASE STUDY

To replace the existing diesel generator option at sample 5 villages, renewable energy sources such as solar PV and biogas sources are selected for the purpose of remote electrification. As India receive large amount of solar radiations in range of the 4 to 7 kWh/$m^2$/day with horizontal intensity 1000 W/$m^2$ and most places have annual sunshine of about 300 days, solar PV is one of the best option for village electrification. Biogas is selected due to locally available waste product at these villages which can be sufficient to meet their electricity requirements. Availability of agriculture wastage, fuel wood, and animal dung produces biogas sufficient to small scale electricity generation. Biogas gives a sustainable and relatively low cost option for fulfilling basic electricity needs in rural and remote areas. To meet the energy demands at villages, sample calculation of array sizing, biogas generation and COE for one of the village Bharatpur is presented bellow in detail. Similar steps and calculation applied to other villages for COE of solar and biogas.

**2.3 Solar PV power generation**

Solar radiations are about 1000 W/$m^2$The efficiency of solar cell assumed to 13% so solar cell of 1$m^2$produces 130W of peak power. A 100 kWp solar plant of 1800 panels of 70 W each produces 75 kWh/h. Assuming peak sunshine hours 4.2 hr/day units generated per day is 315 kWh. Specification of 70Wp module are a) Peak current 4.15 A and short circuit current 4.48 A b) Mismatch factor 0.85 c)battery efficiency 0.8 and charge regulator efficiency is 0.9 d) module voltage is 12V.

3.1.1 Array sizing and total no of modules: From the Table 1, connected load of Bharatpur is 40.755 kW. From connected load, from specification given above and following equations (1) to (5) determines the array size and number of modules required to supply the electrical load of Bharatpur. Require array load and size calculated using following equations.

$$\text{Array load} = \frac{\text{total daily load (kWh/day)}}{\text{battery efficiency x charge regulator efficiency}} \quad (1)$$

Array load = 56.94 kWh/day

$$\text{Array size} = \frac{\text{Array load}}{\text{No of peak hours} \times \text{mismatch factor}} \quad (2)$$

Array size = 16 kWp/day

Total number of module calculated from specification and system voltage is 220V.

No. of series modules = $\frac{\text{system voltage(V)}}{\text{module voltage(v)}}$ (3)

$= \frac{220}{12} = 19$

No. of parallel modules = $\frac{\text{daily load demand(Wh)}}{\text{module daily output(Wh)}}$ (4)

$= \frac{\text{daily hour (Ah)}}{\text{battery charging efficiency x module x derating factor}}$ (5)

$= \frac{(40.75 \times 1000)/220}{0.8 \times 0.85 \times 17.43} = 16$

No of parallel model = 16

No of series model = 19

Total no of modules = No of series Modules x No of parallel Modules = 16 × 19

= 304

**Table 1 Connected load of five villages**

| **Name of village** | | **Bharatpur** | | **Laxmanpur** | | **Ramnagar** | | **Sitapur** | | **Neil Kendra** | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Devices*** | ***Rated power(W)*** | ***No*** | ***Load (kW)*** | ***No*** | ***Load (kW)*** | ***No*** | ***Load (kW)*** | ***No*** | ***Load (kW)*** | ***No*** | ***Load (kW)*** |
| Bulb | 60 | 284 | 17.04 | 221 | 13.26 | 393 | 23.58 | 166 | 9.96 | 617 | 37.02 |
| CFL | 10 | 14 | 0.14 | 2 | 0.02 | 1 | 0.01 | 9 | 0.09 | 12 | 0.12 |
| Tube Light | 40 | 87 | 3.48 | 36 | 1.44 | 154 | 6.16 | 69 | 2.76 | 293 | 11.72 |
| Fan | 60 | 137 | 8.22 | 108 | 6.48 | 190 | 11.4 | 93 | 5.58 | 327 | 19.62 |
| TV | 200 | 39 | 7.8 | 42 | 8.44 | 85 | 17 | 40 | 8 | 133 | 26.26 |
| Radio | 25 | 33 | 0.825 | 25 | 0.625 | 86 | 2.15 | 32 | 0.8 | 79 | 1.975 |
| VCR | 50 | 23 | 1.15 | 27 | 1.35 | 53 | 2.65 | 26 | 1.3 | 43 | 2.15 |
| RF | 300 | 1 | 0.3 | 3 | 0.9 | 10 | 3 | 1 | 0.3 | 22 | 6.6 |
| WM | 500 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 |
| Mixer | 400 | 3 | 1.2 | 2 | 0.8 | 8 | 3.2 | 3 | 1.2 | 31 | 12.4 |
| Street light | 40 | 15 | 0.6 | 11 | 0.4 | 20 | 0.8 | 15 | 0.6 | 35 | 1.4 |
| Computer | 150 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0.3 |
| **Total** | | | **40.75** | | **33.75** | | **69.95** | | **30.59** | | **120.90** |

3.1.2 Battery sizing*:* The battery capacity is decided assuming 5 days of reserve, depth of discharge (DOD) as 80%, temperature derating of 0.85.Total number of batteries is calculated considering individual capacity of battery as 200 Ah.

Capacity of battery calculated using equations (6), (7), (8), (9) as follows

$$\text{Battery capacity} = \frac{\text{Daily load (Ah) x reserve days}}{\text{DOD x temperature derate x rate factor}} \quad (6)$$

$$= \frac{\left(\frac{40.75\text{x } 1000}{220}\right)\text{x } 5}{0.8\text{x } 0.85 \text{ x } 1.33}$$

= 1024 Ah

$$\text{No. of series batteries} = \frac{\text{System voltage(V)}}{\text{battery voltage}} \quad (7)$$

$$= \frac{220}{12} = 19$$

= 19 approx

$$\text{No. of parallel batteries} = \frac{\text{Capacity of battery bank}}{\text{Indivisual battery capacity}} \quad (8)$$

$$= \frac{1024}{200}$$

= 6 approx

Total no of batteries = No of series Battery $\times$ No of parallel Battery (9)

$= 19 \times 16$

= 114

3.1.3 Inverter sizin*g:* After determining the size and numbers of battery next step is to size inverter to supply power to load. Inverter size depends upon the total connected load and efficiency of inverter. Efficiency of inverter assumed as 90%. Using following

equation (10) the size of inverter for Bharatpur village is calculate from data given in Table 1. Total connected load of 40.755 kW indicates output power required by the inverter.

$$\text{Efficiency of inverter} = \frac{\text{Out put power}}{\text{Input power}} \text{ x } 100 \quad (10)$$

So inverter input power calculated from equation (10)

$$= \frac{40.755}{0.9} = 50 \text{ kVA}$$

Inverter input power = 50 kVA

For irrigation pump load of 27.2 kW by using similar steps and formulae the array size calculated

Array size = 11 kWp/day

Total no of modules = 18 x10 = 180

**3.2 Electricity produced from biogas:**

The waste available in the form of cattle dung (Animal dung) and bird dung which can be converted into the biogas. Detail of dung availability [6] of five villages is shown in Table 2. It was found that for Bharatpur there are 997 kg of dung from animal and 427 kg dung from the bird. Total collected dung is 1421 kg but the collection efficiency considered as 75% so net dung collection be the 1068 kg. The important assumption for the waste collection is that 7 kg of dung will be available from buffalo, 1 kg from goat and 0.5 kg from the hen.

Whereas 12 kg of dung produces 1 $m^3$ of biogas Total biogas production from the net dung availability is calculated using the following equations and assumptions describe above.

1 kg gives 0.0833 $m^3$so total wastes of 1068 kg gives 89 $m^3$biogas. Biogas plant of 60 $m^3$capacities is considered in COE calculation. Hence number of biogas plant of capacity 60$m^3$ for Bharatpur (NB) is 2.

As 89 m3 of biogas available and as 1 $m^3$biogas gives 19 MJ [6], electricity generated from biogas found as,

Electricity from biogas (MJ) =89×19=1691 MJ

Conversion of MJ to kWh

Electricity in kWh= 469.722 kWh

Total electricity generated from waste at Bharatpur considering 33 % efficiency is found as 155 kWh/day

**Table 2 Dung availability and biogas production**

| Name of village | Animal dung per day (kg) | Bird dung per day (kg) | Total dung per day (kg) | NET dung (75% collection efficiency) | Total biogas per day (cu-m) |
|---|---|---|---|---|---|
| Bharatpur | 997 | 427 | 1424 | 1068 | 89 |
| Laxmanpur | 1378 | 245 | 1623 | 1217 | 101 |
| Ramnagar | 2064 | 552 | 2616 | 1962 | 164 |
| Sitapur | 1385 | 285 | 1670 | 1253 | 104 |
| Neil kendra | 1059 | 308 | 1367 | 1025 | 85 |
| Total | 6883 | 1817 | 8700 | 6525 | 544 |

**3.3 Cost of energy calculation:**

3.3.1 COE of solar PV: COE for solar depends upon the capital cost of solar panel and balance of system cost (BOS).BOS cost consider cost of battery, inverter and other components required for connection of solar PV system. It is assumed that BOS is 41% of panel cost.

Capital cost of solar system is calculated using following equations

Capital cost = Cost of solar panel + BOS cost

= [watt peak cost + BOS cost] × Array size

Panel cost is calculated from watt peak cost. In the year 2007 Rs 165 was the per watt peak cost of solar PV panel. The array size calculated in section A shows Baratpur village require array size of16kWp/day to supply electrical load.

Panel cost = Rs2640000/-

BOS cost =Rs1082400/-

Putting together cost of panel and BOS cost, capital cost is found as of Rs 3722400/-.

As the Government of India provides subsidy for solar power plant and it is 2/3 of capital cost hence considering subsidy

Cost of subsidy for solar = Rs2481600/-

Net Capital cost = Rs1240800/-

So after calculating the capital cost of PV panel as above next step is to calculate annual generation from PV array.

Total annual generation calculated by assumption of 100 kWp panel gives 75 kWh/h [6]. Hence 16 kWp gives 12 kWh/h of energy and considering solar PV is operated for 3 hours.

Annual generation = 12 $\times$ 3 $\times$ 365 = 13140 kWh

Considering capital cost and net generation, cost of energy (COE) for solar is calculated as

$$\text{Cost of energy (COE)} = \frac{[\text{capital cost}] \times [\frac{PRF}{100} + \frac{O\&M}{100}]}{\text{Total annual generation}} \qquad (11)$$

Where PRF is plant recovery factor and it is 15 % of capital cost and O&M is operation and maintenance cost which is considered as 2 % of capital cost.

Putting values of annual generation, capital cost, PRF and O&M in equation (11)

Cost of energy (COE) for solar PV= 16.05 Rs/kWh

3.3.2 COE for biogas: COE of biogas depends on plant cost and unit fuel cost. The cost of 60 $l$ biogas plant in year 2007 is Rs 302500 per plant.

$$COE = \frac{[\text{capital cost} [\frac{PRF}{100} + \frac{O\&M}{100}] + (\text{annual generation} \times \text{unit cost of fuel})]}{\text{annual generation}} \qquad (12)$$

Capital cost of biogas plant = Cost of 60$m^3$ plant $\times$ NB

NB = Number of biogas plant of capacity of 60$m^3$ for Bharatpur.From section B, NB is equal to 2.

Cost of 60$m^3$plant in 2007 year is given as Rs302500/-

Capital cost of Biogas Plant =Rs605000/-

As considering subsidy given for biogas is 40% of the capital cost is

Capital cost of Biogas Plant= Rs363000/-

Next step is to calculate unit cost of fuel for mode 1) 70 % biogas, 30 % diesel 2) 85 % biogas, 15% diesel

Unit cost of fuel = cost of diesel per kWh + cost of dung per kWh (13)

As fuel consumption in 70 % biogas, 30 % diesel mode is 0.09 L/kWh and cost of diesel in 2007 is 33.25 Rs/L so unit cost diesel/kWh using equation (13)

Cost of diesel for 70 % biogas, 30 % diesel =2.99 Rs/kWh

Similarly the cost of diesel for 85% biogas, 15% diesel calculated as fuel consumption reduced 0.045L/kWh using equation (13)

Cost of diesel for 85 % biogas, 15 % diesel = 1.49 Rs/kWh

Cost of dung is gives as 1.25 Rs/kWh

Unit cost of fuel for 70 % biogas, 30 % diesel = 4.24 Rs

Unit cost of fuel for 85 % biogas, 15 % diesel = 2.74 Rs

As the electricity generated from $60\ m^3$ biogas given is 10 kW and biogas plant is assumed to be operated for 6.5 hours and number of 60 $m^3$ biogas plant (NB) is 2

Annual generation = $10 \times 2 \times 6.5 \times 365$ =47450 kWh

Putting value of unit cost of fuel, capital cost and annual generation in equation (12) for both modes, COE is calculated as

COE 70% biogas and 30%diesel (no subsidy) =6.41 Rs/kWh

COE 85 % biogas, 15 % diesel (no subsidy) = 4.91Rs/kWh

Similarly the COE with subsidy is calculated for both modes as

COE for 70% biogas and 30%diesel = 5.54 Rs/kWh

COE for 85 % biogas, 15 % diesel = 4.04 Rs/kWh

3.3.3 COE of diesel power generatios: COE of diesel power generation calculated as

Capital cost Diesel power plant = Cost of generator/kW $\times$ Size of generator

As cost of generator in year 2007 is 20000 Rs/kW and size of generator is taken as 30% more than connected load hence size of generator is 53kW

Capital cost Diesel power plant = Rs1060000/-

Unit cost of fuel = Fuel consumption $\times$ Rate of diesel/L

As fuel consumption is 0.3 L/kWh and rate of diesel in 2007 is 33.25 L

Unit cost of fuel = 9.975 Rs/kWh

As there is no subsidy for diesel power generation, it is not included in calculations. From capital cost and unit fuel cost values calculated above and equation (12),

COE for diesel power generation= 11.93 Rs/kWh

Steps and calculation presented in section A, B and C, applied for the other villages. Considering the cost of components as per year 2007, 2012 and 2016, year wise COE with and without subsidy has been given in Table 3. In addition to this the battery and number of PV module required for other villages are calculated by applying steps in section A. The details of battery and PV module obtained as per village connected load are as given in Table 4

## IV. RESULTS AND DISCUSSION

Table 3 shows effect of change in COE for the year 2007, 2012, and 2016. As government of India provides subsidy for solar and biogas power generation and its local availability, the use of these sources in comparison with diesel power generation are found attractive for village electrification.

**Table 3 Cost of energy**

| **Source used for electricity** | **COE(Rs/kWh) in year 2007** | | **COE(Rs/kWh) in year 2012** | | **COE(Rs/kWh) in year 2016** | |
|---|---|---|---|---|---|---|
| | ***Subsidy*** | ***No subsidy*** | ***Subsidy*** | ***No subsidy*** | ***Subsidy*** | ***No subsidy*** |
| **DG** | 11.93 | 11.93 | 18.14 | 18.14 | 22.08 | 22.08 |
| **Solar** | 16.05 | 48.15 | 14.71 | 44.13 | 10.21 | 30.64 |
| **70%biogs 30%diesl** | 5.54 | 6.41 | 9.63 | 12.15 | 15.44 | 21.14 |
| **85%biogs 15%diesl** | 4.04 | 4.91 | 7.33 | 9.33 | 12.64 | 18.37 |

In year 2007 the COE of DG is 11.93 Rs/kWh and it goes on increasing in year 2012 (18.14Rs/kWh) and in year 2016 (22.08Rs/kWh) due to increase in diesel cost and installation cost. Whereas COE of solar PV in year 2007 is 16.05Rs/kWh and decreases in year 2012 (14.71Rs/kWh) and in 2016 more reduction in COE (10.21Rs/kWh) because of reduction in panel cost and BOS cost.

Duel fuel mode gives two options for use of biogas as 70%biogas and 30% diesel & second one is 85% biogas and 15 % diesel hence due to reduction in use of diesel in second option the COE is less relative to that of first option. So in year 2007 COE of biogas of both option is very less as compared to solar and DG. But as cost of diesel increase in year 2012 and 2016 the COE of biogas plant is found increased and it is relatively high in year 2016(12.64 Rs/kWh), as compare to solar PV in year 2016 (10.21 Rs/kWh). The size of solar system with number of battery and number PV module required as per connected load of five villages is given in Table 4.

**Table 4 Details of battery and module**

| **Name of village** | **Load (kW)** | **Battery (200Ah)** | **Modules (70Wp)** |
|---|---|---|---|
| Bharatpur | 40.75 | 108 | 288 |
| Laxmanpur | 33.71 | 90 | 234 |
| Ramnagar | 69.95 | 162 | 486 |
| Sitapur | 30.59 | 72 | 216 |
| Neil kendra | 120.90 | 270 | 828 |
| Total | 295.2 | 702 | 2052 |

## V. CONCLUSIONS

The paper presents the approximate financial and technical requirements for the remote area electrification where grid extension is not possible. Due to these available solar and biogas renewable energy source sat site are selected for such isolated areas for electrification. It seems availability of solar radiation at remote location and the dung availability at villages are sufficient to produce electricity according to connected load of all five villages. The cost of energy obtained for solar and biogas in comparison with diesel shows the economically feasible option for rural electrification. The study shows in year 2016 the solar is the economically best options for rural electrification over diesel and biogas hence based on the calculations solar system size for five villages is also presented.

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