Electrification in rural areas of India and consideration of SHS

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Abstract— **Rural electrification is an integral component of poverty alleviation and rural growth of a nation. In India, electricity has not played effective role in the socio-economic growth of village. Government of India has ambitious target of providing electricity to all villages by 2008 and all rural households by 2012. Steps are initiated with Rural Electric Corporation, State Electricity Boards, Reforms in Power sector. Ever increasing demand of electrical energy is causing a large gap in generation and load demand. All the requirement of energy cannot be fully met with conventional grid supply so, an alternative energy source has to be found out for this purpose. Therefore it has become necessary to explore the applications of distributed energy sources which are inevitable to meet the energy requirements. An attempt has been made in this paper to assess the features of rural electrification in India and a simple cost comparison of Solar Home Systems (SHS) with grid supply in deep rural areas.**

Keywords-rural electrification;solar home systems

I. INTRODUCTION

India has one of the fastest growing economics in the world and ranked sixth place in the worldwide consumer of energy. Being the seventh largest country in the world, six thousand villages inhabit 72.2 percent of its human resource (census 2001). About, 40 percent of the total energy is in rural areas. Domestic sector constitutes major energy demand and its consumption accounts for 60 percent of energy used. The main energy sources are coal and oil, whilst hydro, wind, nuclear and biomass provide additional sources. Following are some of the salient aspects having direct and indirect bearings on energy supply, to rural [1] –

- Both the traditional energy and commercial energy are in short supply and the demand supply gap is in increase.
- Pressure on traditional energy resources such as wood is continuously increasing due to growing population.
- Heavy dependence on commercial fuels such as coal and oil as a short term measure for meeting increasing demand is alarming in view of depleting fossil fuels and pollution.
- Energy supply to far–off rural areas is associated with high transportation and transmission losses of about 22.4%.

Thus emphasis should be laid on the auditing of the energy in such a way that ensures affordable, ecofriendly and clean energy. There are two ways of supplying electrical energy to rural areas-one extending grid to near by areas and other distributed generation particularly in deep rural areas. Importance of rural electrification and advantages in the third world discussed [2]. Majority of rural electrification is carried out by the existing grid extension. The need of modifying the existing grid connected supply in rural India [3] [4].

The available renewable technologies] and their economic performance in rural areas of India, indicates the strategic approaches required for large scale penetration of solar home systems [1]. A study of particular emphasis on comparing the costs of hybrid distributed generation systems with conventional grid connections for remote rural villages Kachchh district of Gujarat survey of rural areas [5].

Importance of electricity as a crucial infrastructure input for economic development of the country has been well established. Recent studies of rural electrification indicate the following broad consensus concerning the impact of electrification in the rural areas. [2]

Features of Rural Electrification

Rural electrification is an important component of Integrated Rural Development. In India, it has been given less importance with respect to urban, because of the following reasons.

- Villages are located from 3-80 km away from existing grid or even more.
- They are located in difficult terrain areas like forests, hill areas and deserts.
- The number of households may range between 2 to 200, with a majority of villages having a population below 500.
- 60% of the 5 67000 villages in India have a population of 500 and under and 8% of these are inaccessible. (Source: Census 2001).
- Power demand in villages is quite low due to dispersed distribution of loads. Also rural domestic consumers are mainly peak time consumers, contributing for poor load factors of 0.2-0.3.
- Rural electrification policy by Government of India (Source: Ministry of Power) has identified the importance of this. Electricity is an essential requirement for all facets of our life and it has been recognized as a basic human need. It is the key to accelerating economic growth,

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generation of employment, elimination of poverty and human development especially in rural areas.

- Previous definition of village was (Source: Ministry of Power) - A village will be deemed to be electrified if electricity is used in the inhabited locality, within the revenue boundary of the village, for any purpose whatsoever.

Modified definition of village from 2004-05 is, - A village would be declared as electrified if -

a) Basic infrastructure such as Distribution Transformer and Distribution lines are provided in the inhabited locality as well as the Dalit Basti/ hamlet where it exists. (For electrification through Non Conventional Energy Sources a Distribution transformer may not be necessary).
b) Electricity is provided to public places like Schools, Panchayat Office, Health Centers, Dispensaries, Community centers etc. and
c) The number of households electrified should be at least 10% of the total number of households in the village.

II KEY FEATURES OF GRID CONNECTION

Rural Electrification is not an attractive investment options to the utility .Of the total power generated only 55% of the kilowatt-hours are billed and only 41% of this is collected. Rural people do not have access to electricity and rely almost exclusively on wood, agricultural residues and animal dung to meet their energy needs. These people basically have three options or scenarios for the provision of electricity:

- Utility network grid-connection (via grid extension) [2];
- Distributed-grid systems (often known as mini-grid systems)
- Stand-alone systems

In India, rural electrification is carried out mainly by grid connection. The method of 'connecting a village to be electrified to the nearest village that has been electrified' has led to an inefficient, unmanageable distribution network. (Table I) This has resulted in the following problems.

1) Average Cost of grid connection increases with distance from grid (Fig 1)(Chakrabarti *et al* 2002).Rural electrification cost comprises of high capital cost and high operating cost components. The effect of transmission and distribution losses may further increase the delivered cost. It increases cost about Rs1 per kWh per kilometer of expansion to individual village. A recent estimate for a Gujarat case study, based on Gujarat Electricity Board data, put the true cost of delivery to rural areas at over Rs.9/kWh. [3].
2) Aggregate and technical losses in India amounts to 50 percent (Table II).
3) Number of average 100 hour Customer Hour Lost (CHL) per month due to both scheduled and unscheduled load shedding by grid. (Fig. 2).
4) Due to several reasons, still 157 million households are not having access to electricity. (Fig. 3)
5) Based on a preliminary examination of the relative economics, a remote village is generally taken as one located at least 3 km from the existing grid in hill and forest areas, and 7 km in the plains.

Table I Transmission & distribution line details as on 31-3-2010
(Source: Rural Electric Corporation)

Transmission line 220 kV	1,03,724 ckm
Transmission line 400 kV	56,090 ckm
Sub stations 220kV	1,38,312
Sub stations 400 kV	73,175

It is estimated that 125,000 villages (21 % of all villages) currently lack electrification in India (Sharma, 2007), with about 18,000 to 24,500 villages classified as too remote or inaccessible, for which electricity supply from the grid may not be possible in the near future (Nouni *et al.*, 2007, 2008).

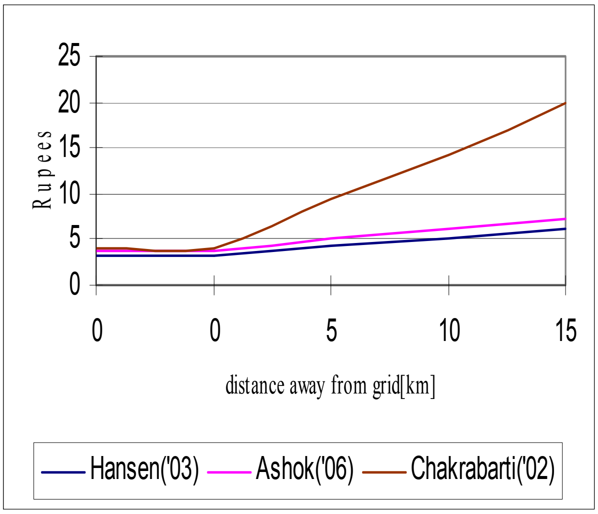

Fig 1. Cost of grid electricity [Rs/kWh] with distance from grid [km] (Chakrabarti *et al* 2002).

Table II. Percentage Aggregate Technical & Commercial losses in rural side (Source: Central Electrical Authority

Aggregate Technical & Commercial loss	Percentage
south grid	4
state grid	4
33 kilovolt	5
11 kilovolt	5
LT dist	20
collection	12

Therefore, distributed electricity production, defined as electricity-based production within the village that is not linked to a grid or to transmission or distribution networks provides a plausible medium-term solution to the electricity accessibility issue (Sharma, 2007). The government of India has identified the goal of electrifying every village in India by 2012, giving priority to distributed generating plants for villages too remote for extension of the conventional grid lines (Ghosh *et al.*, 2004).. Furthermore, where villages are presently connected to the grid, the current supply of electricity is sporadic and in many regions not up to acceptable standards.

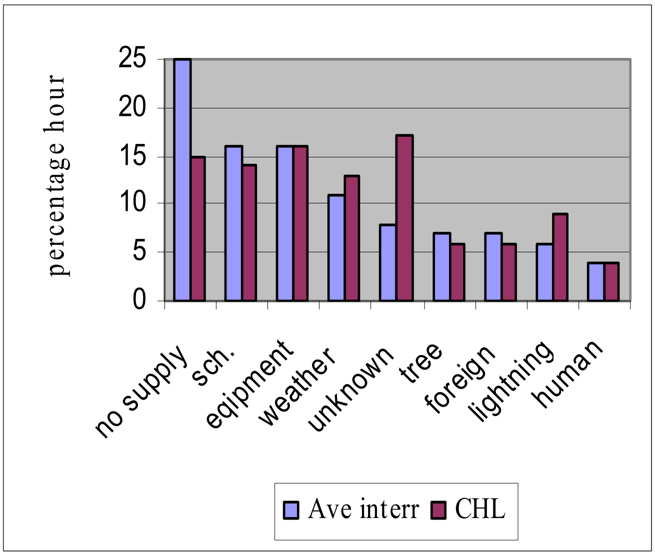

Fig. 2 Customer hour lost and average interruptions
(Source: Central Electrical Authority)

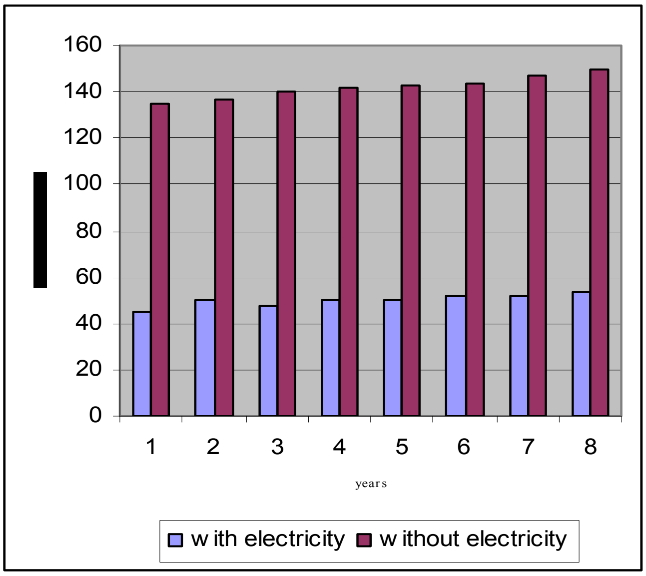

Fig. 3 Electricity supply to rural households in millions
(Source: Central Electrical Authority)

The advantages of distributed generation are numerous, including avoiding reliance on state utilities, which are not able to provide reliable supply or access. Other advantages include decreased reliance on fossil fuel-based electricity generation, decreased loss in transmission, which is currently estimated to be 40% in India, and direct employment opportunities within the villages, the sites of equipment and operation (Sharma, 2007). Hence power planners are forced to think of supplementary or alternative electrical energy supplies to these areas. The Energy Information Administration defines renewable energy as "energy that is naturally replenishing but flow-limited. Renewable energy is virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time". Thus available options for rural electrification are- solar, wind, diesel and biomass. (Fig. 4 and Table III).

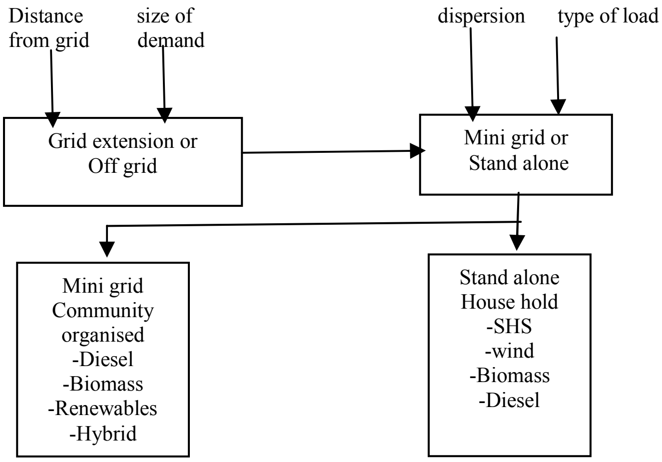

Fig. 4 Technology options for off grid rural electrification

Table III.Options for rural electrification in India
(Source: Christopher Joshi Hansen & John Bower Oxford Institute for Energy Studies EL 05 October 2003)

Suitable Options	Percentage Efficiency	Approximate cost [Rs/ kWh]	Influencing Factors
SHS	13-18	10-12	on site generation, modular in size, battery life
Diesel	15-25	10-15	availability, escalating fuel cost, environmental concerns, pollution control board permission
Wind	25	4-8	seasonal ,bulk power source, away from load, medium wind profile low plant load factor
Biomass	15-20	2 -4	availability, maintenance
Grid	--	5	voltage profile, Consumers Hours loss

Being tropical country is best suited for solar energy. Other key factors are –

- availability of solar energy for about 300 to 320 days in a year (Purohit *et al.* 2002) and it receives about 5,000 trillion kW h of solar energy in a year (MNES 2005).
- reduction in the cost of PV cell to Rs 170-200 per watt in 2008 from Rs 1000 in 1998.
- On site generation and no transmission and distribution losses.

- customer is the owner of his or her own power-generating system
- no fuel cost is involved and the production of power is environmentally friendly.
- suited for roof top generation, generation at site and hence proximity to utilities as compared to mini grid.
- the systems are suitable for any part of the India,
- Proven technology of panel, battery and controller
- solar PV systems are durable with little maintenance

IIIV. ADVANTAGES OF PV SYSTEM

PV technology is identified as most environment friendly technologies. It requires only sunlight and no other energy fuel. [6][7] Being modular in design, the capacity can be increased to meet additional demand. It is easy to dismantle and reconfigure these systems for other applications. PV systems require little maintenance. These components can be manufactured and assembled locally.

1) Environment friendly as they do not emit gaseous and liquid pollutants.
2) Can be easily transported, assembled and installed in remote areas.
3) Produce DC electricity that can be stored in batteries
4) Zero fuel usage and Noise free
5) Robust, reliable, weather proof and having long life of 25 years with proper maintenance.

Despite these advantages, PV system has following challenges.

- High capital cost, makes the system cost-prohibitive.
- Few types of devices can be operating using PV.
- PV systems being less competitive compared to other sources and are not suitable source for meeting large loads.
- Silicon is the second most common element on the earth's crust. The processes required to extract silicon of suitable quality, and the various refining stages, are very energy-intensive and not environment friendly.
- Disposal of battery is a environmental issue
- Higher potential of these systems is mainly in remote rural areas where grid connection is not cost effective.

Thus regular increase in the cost of grid electricity price, a fall in marketing costs for PV modules and the discovery of break through in solar technologies key points of PV system.

PV panel for a rural house

I) The average energy consumption of a household is influenced by many factors-Like construction and size of house, climate, season, size of house, and size of family (census 2001 average 5.3 persons per house in rural area with 3 rooms).

II) Arid regions in India receive plentiful solar radiation of 4-7kwh per square meter with the potential availability of 20 MW per square kilometer. Average solar insolation available is 5 kWh per square meter. (Source: Indian Renewable Energy Development Agency). IREDA is planning to electrify 18,000 villages by year 2012 mainly through solar PV systems.

III) Availability of solar insolation in Dharwad, (Karnataka state) rural indicates that there is ample scope for using PV in rural areas (fig. 5) and additional 2.71 kWh energy can be saved in tubular batteries with one panel of 35 W , i.e. the system is able to supply power to the load for 3 days even if the charging is drastically reduced due to rain or other natural calamities. Also the depth of discharge for the battery is taken to be 75%.

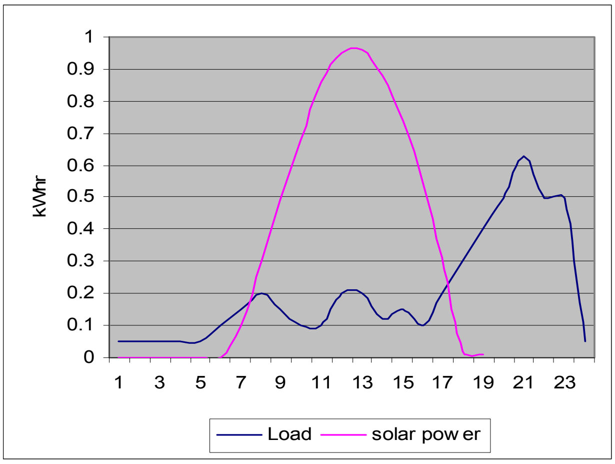

Fig 5 Solar radiation max [kWh/square meter] and load [kWh] verses time of day in Indian village

IV) Government of India provides central financial assistance for remote village electrification programs. (Table IV).

V) Every kWh of generated solar power prevents the release 0.7 kg of carbon dioxide. Crystalline silicon PV panels prevent 2,000 kg -3,000 kg of carbon dioxide emissions per square meter for a 25years life expectancy of the panel. Using PV in areas of high solar insolation could reduce carbon emissions by as much as 450 Million Metric tons during the next 25 years Every gigawatt of electricity generated by PV rather than coal was estimated to prevent up to 10 tons of sulfur dioxide, 4 tons of nitrogen oxide, 0.7 tons of particulate matter (including cadmium and arsenic), and up to 1,000 tons of carbon dioxide being emitted into the air .

VI) Electric lighting (up to 200 times brighter than kerosene lamp directly improves the quality of life. It allows children to study in the evening and women to gain some precious time for them or to extend income generating work into the evening hours (Domdom *et al* 2000). Scarce availability of kerosene and high cost of diesel, solar power is making inroads amongst villagers.

Table IV Central financial assistance for remote village electrification (Source; Government of India No15/6/2006-07-RVE)

Home lighting Models	Specifications	General Category States(Rs)	Special Category States(Rs)
Model-I	18W module,2 light	5895	6165
Model-II	37W module,4 light	11250	11250

VI) Mathematical modeling of 75 Wp array using MATLAB programming is shown in the fig. 6.

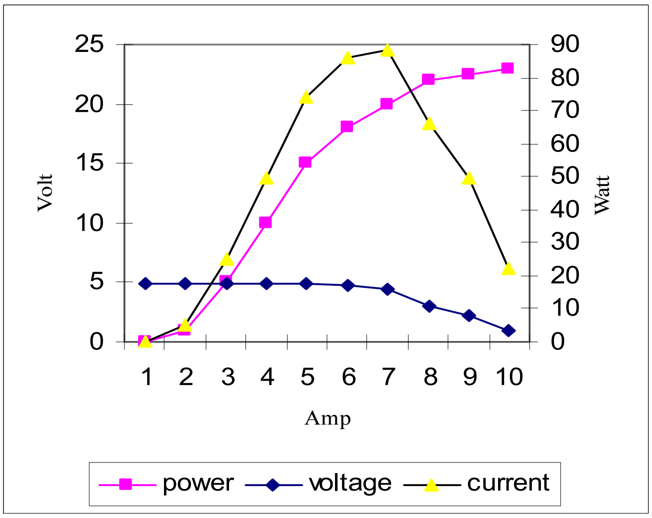

Fig. 6 MATLAB Mathematical model of 75Wp solar array

VIII) PV cost includes two components-PV system cost and Balance-of-system. System cost mainly includes module, delivering d c supply and Balance of system includes other ancillary equipments like power storage, power conditioning, mounting and site specific requirements. Decreasing trend of PVSHS cost by 20% and increasing trend of growth are resulting in encouraging results in India (fig.7).(MNES Report 2008).

IX) The main barriers to large penetration of SHS consists of (Purohit and Kandpal *et al* 2005) -

(a) nature of the solar energy resource high initial investment and still higher costs of these systems to the end users as compared to the conventional
(b) lack of strong marketing network and excellent market-support infrastructure
(c) the market for SPV home lighting systems is currently supply driven as user's needs have not been full
(d) emphasis is more on technology development rather than product development to effectively meet the user's need and,
(e) awareness level of the benefits of SHS is not up to expected level.

IV. SHS SYSTEM FOR RURAL HOUSE- A CASE STUDY

Number of panels

Electricity consumption has been estimated for electrified areas, with use varying from 0.33 kWh per household per day for landless households to 0.84 kWh per household per day in larger landholdings for lighting purposes (Ramachandra *et al.*, 2000b). (Table V)

Taking average kWh per day as 0.58 and accounting for system losses 10% and voltage drop of 0.5%,

Wattage required=580X 10.5% =609 Whr

75 watt-peak (Wp), 12 volt panels required=2 panels

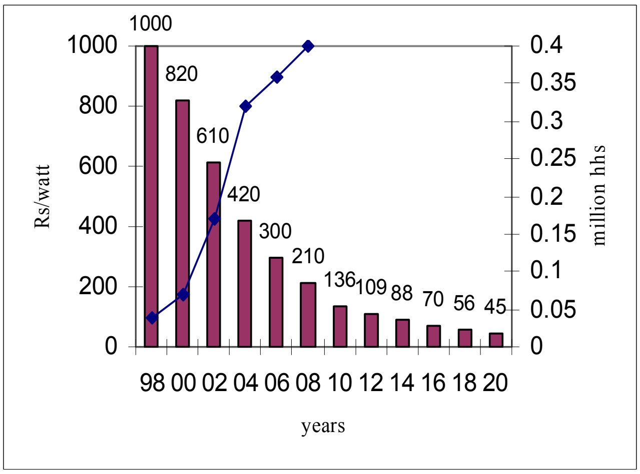

Fig 7 Reduction of cost [Rs / Watt] and Increase in SPV lighting systems [Millions] installed in India

Table V. Average load of a household (Ramachandra *et al.*, 2000b)

utility	watt	hour	Total [Whr]
Lamps (three)	40	2.5	300
Tape/Radio	20	3	60
TV	80	3	240

Total daily consumption=600 watt-hr

The mathematical modeling of 75 Wp, indicates satisfactory performance (fig.6) and with this additional amount of electrical energy is stored in the batteries.

Battery size required for 3 days autonomy=181.5,-i, e- 3

Hence, 75 Watt, 2panels, three batteries of 60Ahr are required.

PV panels generate kWh per day=6 hrs X 2 panels X 75 Watt=0.9 kWh

PV panels generate 297 kWh per year in 330 days and 7425 kWhr in 25 years.

Electricity generated in 25 years is 1.856MW with carbon dioxide reduction of 5197.5 kg per year and 130 Metric Ton in 25 years.

Cost

There are different methods like payback period (PBP), net present value (NPV) etc..The present method only focuses on cost comparison of SHS with the grid cost.

a) Panels=75 watt x 2 panels X 170 Rs per watt=Rs25500
Batteries 60 Ampere-hour=3XRs 5500 per battery=Rs 16500
Charge controller=Rs. 800 Wiring=Rs. 3000
Inverter=Rs. 7000 Total cost=Rs. 52800

Maintenance cost =Rs. 100 per year

In 25 years of life cycle battery changing cost=3 times X 3 X 5500 Rs. per battery =49500

Life cycle cost =Rs. 52800+25X 100+49500=Rs.104800

b) Subsidy given by MNRE=2X2X11500=Rs.46000

Total cost borne by consumer=Rs104800-Rs 46000=Rs.58800
Cost per kWh=58800/7425=Rs. 7.91
Cost Rs.11.01 with 50% of subsidy reduced and Rs.14.11 without subsidy.

Cost of Grid supply

Cost per unit for grid electricity (Chakrabarti *et al* 2002) =Rs. 5.00
Annual power required=0.840X365=306 units
Total amount to be paid for grid electricity=5x306= Rs.1530
Cost of conventional grid for 25 years=1530 X 25=Rs.38250
Cost of UPS (2 hour battery backup)=7000+4500=Rs. 11500
Hence total cost of the grid=11500+38250=Rs. 49760
Cost per kWh=49760/25X306=Rs. 6.5

As the distance from grid increases, cost per unit increases. (Fig.8). The percentage increase of unit in grid cost per year about to 15 percent is not considered in this calculation.

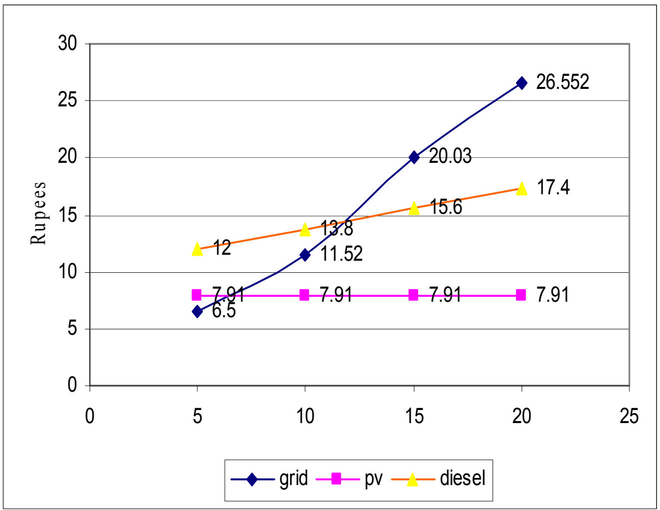

Fig. 8.Comparision of Grid Cost (Rs/kWh), PV and diesel (Rs 37 per litre) with Distance away from grid (km)

a) SHS cost is economically viable alternative to grid cost after a distance of 6.08 km from grid.
b) SHS cost is economically viable with50% subsidy and without any subsidy after a distance of 8.64km and 10.85 km from grid respectively.
c) Developments in PV technologies may lead to cheaper PV systems possibly with lower life expectancy and efficiency than present systems[8].
d) It is assumed that the average power of an individual SHS will increase for the next 30 years from 50 to 300 W, due to an increase in wealth, lower PV system costs etc.

SHS installation to meet the load requirement is cheaper than the grid electric supply. Inclusion of power conditioning equipment to improve quality of power to the grid supply further aggravates the difference and makes SHS system as the energy source

V. CONCLUSION

Rural electrification is a 'selective catalyst' to improve agricultural productivity through mechanization and is essential for many rural activities. It works best when it is complemented by social and economic infrastructure development. In India, 5 lakh SHSs have been deployed till December 2007, and Government of India started National Solar Mission 2010. This aims promote programmes for off grid applications, reaching 1000 MW by 2017 and 2000 MW by 2022, in three different phases. Recent programs are showing good results but more promising new approaches need to be tested to determine if they can address poverty, equity, environmental and public health concerns in the context of ongoing global restructuring of energy industries.

There is a vast scope for utilising of solar photovoltaic energy in India. With continuing research and development and cost reduction it can become the most potential energy source. With a clear renewable energy policy in place, India is the forerunner in this sector. There is room for manufacturers, foreign investors, local financial and institutional agencies and others. Solar energy can be one of the thrust areas due to its accessibility through the country in sufficient quantity. For we owe it to ourselves and our children to provide for sustainable development with due regard to our ecology. Renewable energy is nature's resource and we must use it for human kind in consonance and harmony with nature. Being self-involved, self invested, self maintained and self managed system it is more efficient and self- reliant.

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