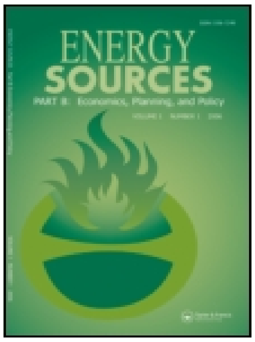

Energy Sources, Part B: Economics, Planning, and Policy

ISSN: 1556-7249 (Print) 1556-7257 (Online) Journal homepage: www.tandfonline.com/journals/uesb20

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To cite this article: T. Krishnaiah, S. Srinivasa Rao & K. Madhumurthy (2012) The Life Cycle Cost Analysis of a Solar Stirling Dish Power Generation System, Energy Sources, Part B: Economics, Planning, and Policy, 7:2, 131-139, DOI: 10.1080/15567240903047566

To link to this article: https://doi.org/10.1080/15567240903047566

Published online: 19 Nov 2011.

Energy Sources, Part B, 7:131–139, 2012

ISSN: 1556-7249 print/1556-7257 online
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The Life Cycle Cost Analysis of a Solar Stirling Dish Power Generation System

T. KRISHNAIAH,[1] S. SRINIVASA RAO,[2] and K. MADHUMURTHY[2]

[1]Department of Mechanical Engineering, GND Engineering College, Bidar, India
[2]Department of Mechanical Engineering, National Institute of Technology, Warangal, India

Abstract *In this article, the techno-economic viability of a Stirling dish power generation system is explored and compared with a diesel generator for Indian conditions. A life cycle cost analysis is carried out over the system lifetime. From the life cycle cost, the unit cost of energy generation is estimated to be INR10.35/kWh for a Stirling dish system and INR11.40/kWh for a diesel generator. The payback period is computed as 9.5 yr for the Stirling dish system and 4.4 yr for the diesel generator. Then sensitivity analyses are presented, which further explore system comparisons as certain base-case assumptions like capital cost, diesel fuel cost, discount rate, and fuel escalation rate are varied. The results show the Stirling dish power generation system to be more cost-effective at low-power ranges of electrical energy supply to the rural communities in India.*

Keywords diesel generator, economic viability, life cycle cost, sensitivity analysis, Stiring dish system

1. Introduction

The rapid depletion of our natural resources and the increasing demand for energy has focused attention on harnessing energy from renewable energy resources. These sources can create a significant impact in the generation of grid electricity due to the progress made in biomass power, wind power and small hydro power in the last few years. The Ninth FiveYear Plan (Government of India, 1999) reported that the demand for electricity in India is growing approximately at 8% per year. The Ministry of Power Blueprint for Power Sector Development (2001) stated that the 16th electric power survey conducted by the Central Electricity Authority concluded that India would need one lakh megawatt generation capacity by 2012. Accordingly, the Ministry of Power (2003) has prepared an action plan for the implementation during the Tenth and Eleventh Five Year Plans. India still has about 80,000 unelectrified villages. Out of these, 18,000 are remote villages where

Address correspondence to T. Krishnaiah, Department of Mechanical Engineering, GND Engineering College, Bidar 585 403 India. E-mail: Krishnaiaht123@gmail.com

the grid cannot reach and alternative strategies for providing power to these tribal villages are to be worked out (Pillai, 2005). The supply of electricity produced by conventional methods to rural and remote villages is gradually recognized as not only uneconomic but also unmanageable. Alternatively, the use of non conventional renewable energies is proving to be more viable and more efficient in the context of total electrification (Sinha and Kandpal, 1991). Research and development exercises over the years have established solar energy as a potential source of renewable energy.

A life cycle cost analysis involves the analysis of the costs of a system over its entire lifespan. Typical costs for a power generation system include initial capital investment, operation and maintenance costs, and replacement cost. Life cycle cost is a useful tool to compare the unit cost of energy of technologies with different cost structures. The life cycle cost (LCC) economic model provides better assessment of the long-term cost effectiveness of a power plant than can be obtained with only first cost decisions. In India photovoltaic cluster electrification has already been tried in places like Lakshadweep and Sagar island in West Bengal (Chakrabarti and Chakrabarti, 2002). Koner et al. (2000), Kolhe et al. (2002), and Srinivasan, 2007 have reported studies on some economic aspects of photovoltaic power generation in India. Celik (2006) has designed a photovoltaic house and assessed techno-economic feasibility of a grid-connected photovoltaic system in Turkey. Kannan et al. (2004) performed a study to quantify energy use and the cost of power generation using life cycle cost analysis for a typical oil-fired steam turbine plant in Singapore. Singal et al. (2007) presented a techno-economic study using renewable energy sources such as biogas, biomass gasification, and solar photovoltaic systems for electrification of a remote island having a cluster of five villages in India. Solar thermal electricity generating systems are proven renewable technologies and often a cost-effective way to produce electricity from solar radiation. Stirling dish systems are characterized by high efficiency, modularity, autonomus operation and inherent hybrid capability. The Stirling dish unit achieved the world's highest peak solar-to-electric power conversion efficiency of 29–30% (Stone et al., 1995).

The objective of the present study is to investigate the techno-economic viability of solar dish-based technologies for decentralized power generation for Indian conditions and to compare it with a conventional system, the diesel generator. A computer simulation program is developed to evaluate the life cycle cost and unit cost of energy over the operation life of the power plant. A sensitivity analysis is carried out to explore system comparisons as certain base-case assumptions like capital cost, diesel fuel cost, discount rate, and fuel escalation rate are varied.

2. Life Cycle Cost Analysis

Solar energy conversion systems are characterized by high initial costs and low annual operating costs. To study the economic feasibility of a system, different methods can be used to evaluate the different figures of merit of the systems, such as the annual cost (AC) method, net present value (NPV) method, LCC method , the payback period method, etc. The method employed for the economic analysis in the present study is life cycle cost method. In the present work, the life cycle cost of the power generation system has been evaluated by using the following cost analysis model:

$$\mathrm{LCC} = \mathrm{CC} + \mathrm{OMC} + \mathrm{RC} \tag{1}$$

All the costs in the cost analysis model are converted to present worth value as follows for the single payment and uniform series, respectively:

$$P(d,n) = \frac{X}{1+d)^n} \tag{2}$$

$$P(d,n) = \frac{A[1-(1+d)^{-n}]}{d} \tag{3}$$

Life cycle cost of the power generation system is converted into a series of amortized annual payments of equal amounts by using the cost annuity method. The conversion takes place by multiplying LCC by capital recovery factor (CRF). The life cycle unit cost of energy (UCE) is calculated as follows:

Amortized annual payment, AAP,

$$\text{AAP} = \text{LCC} \times \text{CRF} \tag{4}$$

where CRF is evaluated as:

$$\text{CRF} = \frac{d}{1-(1+d)^{-n}} \tag{5}$$

$$\text{UCE} = \frac{\text{AAP}}{\text{Annual energy production}} \tag{6}$$

The payback period is the number of years necessary to exactly recover the initial investment. This calculates the requirement of proposal to return their original investment from the savings they generate in a specified period of short duration. A payback period method ignores depreciation and interest rate.

The payback period is estimated as:

$$\text{Payback period} = \frac{\text{CC}}{\text{Net annual savings}} \tag{7}$$

3. Life Cycle Cost Analysis of a Stirling Dish System

The LCC of a Stirling dish power generation system includes initial capital investment, operation and maintenance costs, and replacement cost. The initial capital investment is the cost of manufacturing the concentrator, receiver, engine, generator, cooling system, electrical system, land cost, shipment of the system to the site, site preparation, system installation, balance of plant and a 30% profit. System and component costs as projected by Sun Lab (Stone et al., 1995) are assumed. Operation and maintenance costs include cost of labor, material, maintenance, taxes, insurance, etc. Replacement cost includes the cost of replacement of the battery and is a function of the number of replacements over the plant lifetime. Using this cost information, an estimate of life cycle cost and the unit cost of energy over the lifetime of the plant are calculated.

4. Life Cycle Cost Comparison of a Stirling Dish System With a Diesel Power Generation System

Solar dish-based technologies are compared with a diesel generator for decentralized power generation. A diesel generator has a low initial capital investment compared with a Stirling dish system. On the other hand, the Stirling dish system uses no fuel and has a very low maintenance cost. The LCC method has been used for economical evaluation in the present work. Sizing of the diesel generator is based on daily energy demand over a year. The load factor of the diesel generator (DG) set is taken as 0.45. The load factor is low because of the technical problems associated with a diesel generator. The required installed capacity should be more than the designed load capacity to provide for the surges generated due to inductive load. The initial capital investment is the cost of a diesel generator, which is INR 6,500/kW (US$ 163/kW), which is lower in India. Operation and maintenance costs include the cost of labor, maintenance, taxes, insurance, etc. A genset-user manual (Kirloskar Green Power Ideas, 2006) has suggested the sample maintenance schedule of engine oil and filter change for every 400 h of operation, decarburization for every 1,200 h of operation and engine overhaul for every 3,000 h of operation for a continuously running diesel engine. It requires 22 oil changes, 4 decarburizations and 0.75 overhauls per year. Replacement cost includes the cost of replacement of a 24-volt battery which is a function of the number of replacements over the system lifetime. A sensitivity analysis is conducted to examine the effect of varying the base-case assumptions for several parameters on the uncertainty of cost estimate.

5. Results and Discussion

LCC of a Stirling dish power generation system is compared with a diesel generator set for decentralized power generation. Technical and economic parameters for the base-case of the investigated power plants are summarized in Table 1. A computer simulation

Table 1
Technical and economic parameters for the base-case

Parameter	Value
Capacity of Stirling dish (SD) system	25 kW
Capital cost of SD system	INR. 130240/kW
O&M costs of SD system	INR. 291253/yr
Lifetime of SD system	30 yr
Capital cost of DG set	INR. 6500/kW
O&M costs of DG set	INR. 266460/yr
Lifetime of DG set	6 yr
Battery cost	INR. 14000
Battery average life	1200 cycles
Discount rate	10%
Diesel cost	INR. 37/L
Fuel escalation rate	5%
Fuel consumption	9.66L/h

Source: Sun Lab Kirloskar Oil Engines.

Table 2
Results

	Sterling dish system	DG set
LCC	INR 6,045,170	INR 8,219,540
AAP	INR 641,266	INR 1,887,264
AGEE	62,060 kW	165,564 kW
UCE	INR 10.35	INR 11.40

program is used as a tool for the estimation of the unit cost of energy. The results are given in Table 2. The unit cost of energy generation is estimated as INR10.35/kWh for the Stirling dish system and INR11.40/kWh for the diesel generator. The payback period is computed as 9.5 yr for the Stirling dish system and 4.4 yr for the diesel generator. The Stirling dish system is more expensive to install and has considerably lower operating and maintenance costs than conventional alternatives. In order to quantify uncertainty in the system cost estimates, a sensitivity analysis is conducted and the effect of varying the base-case assumptions (where the base-case costs are those given in Table 1) like capital cost, diesel fuel cost, discount rate, and fuel escalation rate on cost estimate has been investigated. The results of the sensitivity analyses are shown in Figures 1–4.

5.1. Sensitivity—Capital Cost

Figure 1 shows the variation of the unit cost of energy as the capital cost is varied. Since the start of the development of Stirling dish systems in 1980, evolutionary advances have taken place and the capital cost of the system is reduced from 12,576 $/kW to 2,831

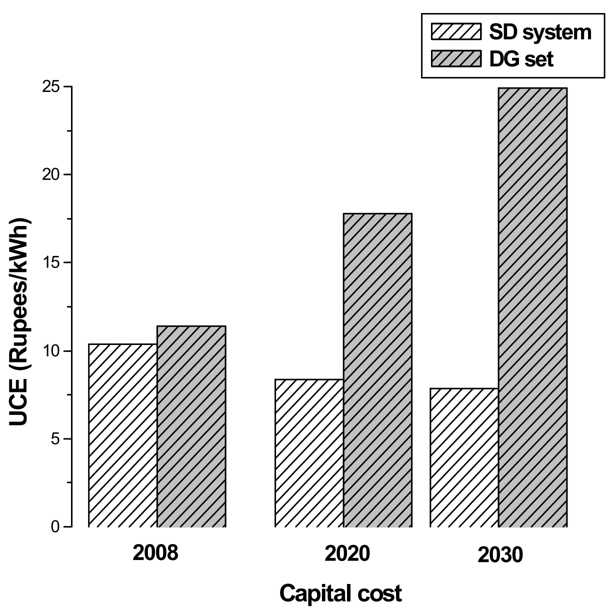

Figure 1. Variation of UCE for SD system and DG set with capital cost.

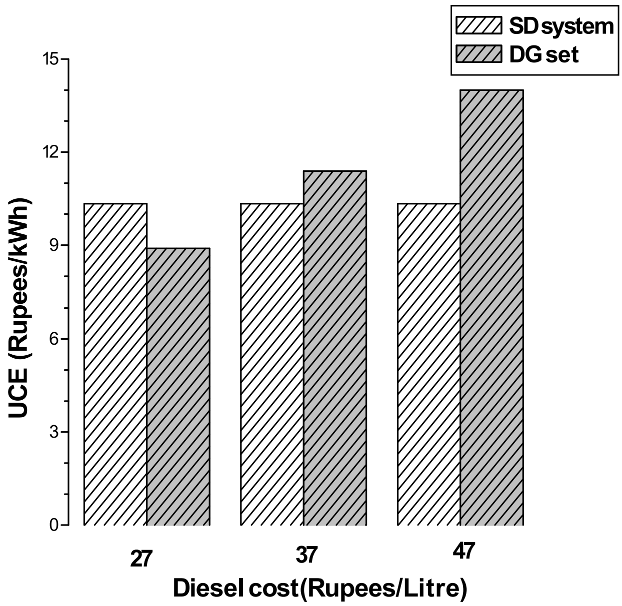

Figure 2. Variation of UCE for SD system and DG set with diesel cost.

US$/kW. This has contributed to a significant decrease in the Stirling dish electricity price. With commercialization of dish/engine technology, the cost of the concentrator, receiver, and controls would decline in the future and the LCC of electricity generation from Stirling dish systems reduces. Diesel engines are already commercialized and no significant change in the capital cost is to be expected in the near future. As time passes

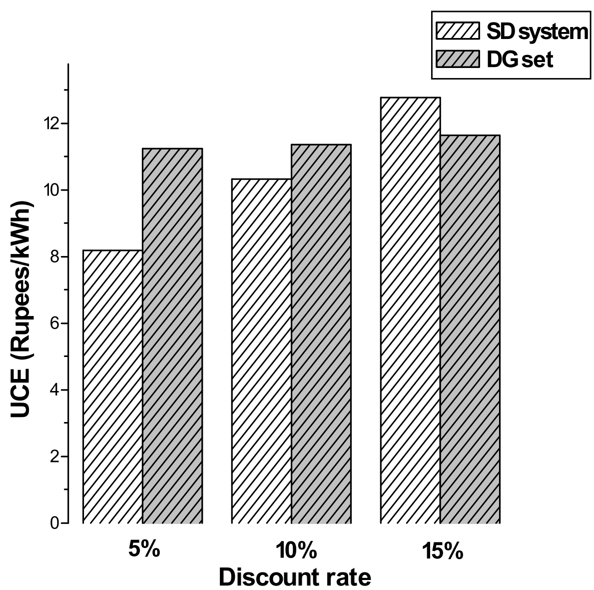

Figure 3. Variation of UCE for SD system and DG set with discount rate.

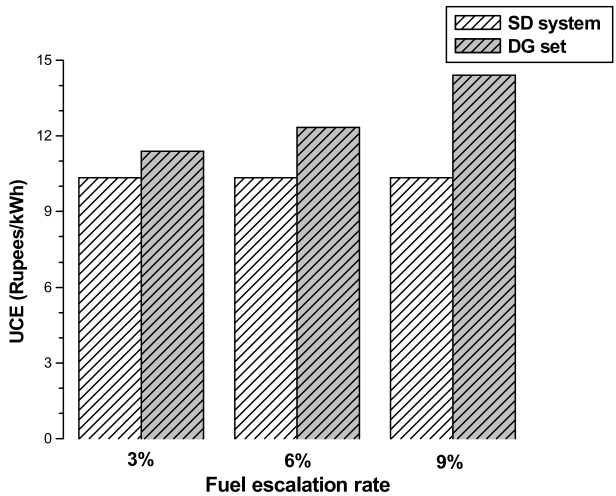

Figure 4. Variation of UCE for SD system and DG set with fuel escalation rate.

the cost of diesel fuel will become higher and the cost of electricity generation from a DG set increases. It is observed that UCE of Stirling dish energy will be significantly cheaper than a DG set in 2020 and 2030.

5.2. Sensitivity—Diesel Fuel Cost

Figure 2 shows the changes that occur in unit cost of energy as the cost of diesel fuel varies from INR 27/l to INR 47/l. It shows that if diesel cost is INR 27/l, the power generated by a diesel generator is cost-effective. It also shows that at a diesel cost of INR 37/l and INR 47/l the Stirling dish energy is cheaper as compared to that of the DG set. In remote areas, where fuel transportation over a long distance is required, power generated by a diesel engine becomes more expensive. Diesel is a highly subsidized product in India. The cost of diesel goes higher when the Indian government removes subsidies at the customer's end. Subsequently the SD system will be more attractive.

5.3. Sensitivity—Discount Rate

Figure 3 shows the role of the discount rate for the calculation of unit cost of energy. The Stirling dish system shows a greater decrease in life cycle cost than that of the DG set for decrease in discount rate. This is due to the high initial cost of the Stirling dish system. It is observed that a little effect of its variation on UCE of the DG set, from 10% to 15% as the initial capital cost, is less. It is found that the Stirling dish energy is cheaper than that of the DG set at a 5% discount rate. It is observed that at a 15% discount rate the DG energy is cheaper than that of Stirling dish system.

5.4. Sensitivity—Fuel Escalation Rate

Figure 4 shows the variation of the unit cost of energy as the fuel escalation rate varies from 3% to 9%. The Stirling dish system energy cost is not much affected by fuel escalation rate. DG set energy cost is highly dependent upon the fuel escalation rate.

The price of crude oil and the foreign exchange reserves of the country are some of the factors that affect the fuel escalation rate.

6. Conclusions

The LCC method has been used for economical evaluation and comparing the stand alone Stirling dish system with a diesel power generating system. From the LCC analysis, the cost of electricity generation was calculated to be INR 10.35/kWh for the Stirling dish system and INR 11.40/kWh for the DG set. Further significant cost reductions can be expected in the near future for solar thermal dish systems. The cost of electricity generation of the DG set primarily depends on the price of diesel. Solar Stirling dish power generation is cost-effective in comparison with the DG set for decentralized power generation, even after considering subsidy on the price of diesel. The payback period was computed as 9.5 yr for the Stirling dish system and 4.4 yr for the diesel generator. Solar Stirling dish power generation was found to be an economically viable technology at low-power ranges of electrical energy supply. Moreover, the solar power generation does not create any adverse effect on the environment. A sensitivity analysis has been conducted and the effect of varying the base-case assumptions like capital cost, diesel fuel cost, discount rate, and fuel escalation rate on the cost estimate has been investigated.

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Nomenclature

A	equivalent amount for single payment
AGEE	annual generated electrical energy

AAP	amortized annual payment
CC	capital cost
CRF	capital recovery factor
d	discount rate
DG	diesel generator
LCC	life cycle cost
OMC	operation and maintenance costs
n	lifetime
RC	replacement cost
UCE	unit cost of energy
X	equivalent amount for uniform series