Techno-economics of micro-hydro projects for decentralized power supply in India

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Abstract

Results of a techno-economic feasibility evaluation of few micro-hydropower (MHP) projects being planned and implemented for decentralized power supply for remote locations in India are presented. The capital cost of such projects (including cost of power evacuation and distribution system), cost per unit of rated capacity, and relative cost of different sub-systems of MHP projects in the capacity range of 10-100 kW have been analysed. Unit cost of delivered electricity for these MHP projects has been estimated. Measures of financial performance for one of the MHP projects have also been determined. Breakeven values for useful life, plant load factor, and unit cost of electricity to the user have also been estimated for the same project.

Keywords: Micro-hydropower; Unit cost of electricity; Measures of financial performance

1. Introduction

The all India installed capacity of electric power generating stations under utilities was 107,533.7 MW as on 31.1.2003 of which contributions of hydro, thermal, nuclear and wind sectors were 26,660.23, 76,525.11, 2720 and 1628.36 MW, respectively (MOP, 2003a). Though the total hydropotential in the country is estimated at 150,000MW, only about 17.8% of it has been exploited so far which contributes about 24.8% to the total power generating installed capacity (MOP, 2003b). About 5.48% of total hydropower generating capacity is contributed by 453 small hydropower (SHP) projects installed in the country as on 31.12.2002. These projects contribute 1463 MW to the total installed electricity generating capacity of the country (MNES, 2003). In India, SHP projects have been classified as: (i) micro-hydro (up to 100 kW), (ii) mini hydro (101 kW to 1 MW) and (iii) small hydro (1-25 MW) by the Central Electricity Authority (CEA) (AHEC, 2003). However, the term 'SHP' is used to describe all hydro projects up to 25 MW capacities. The Ministry of Non-Conventional Energy Sources (MNES) has created data base for 4215 SHP potential sites in 29 States and Union Territories with an aggregate capacity of 10,279 MW out of a total estimated potential of 15,000 MW (MNES, 2003). A substantial fraction of SHP capacity installed in India is contributed by micro-hydropower (MHP) projects.

The history of SHP development in the country is more than 120 years old. In the initial phase of hydropower development, most of the projects were only in SHP category. The first SHP project of 130kW capacity was set up in the country at Sidrapong near Darjeeling in the state of West Bengal. The earliest two MHP projects implemented in the country were of 40 kW capacity and 50 kW capacity respectively at Chamba in 1902 and at Jubbal in 1911. In the absence of high voltage transmission lines, these and other SHP projects were set up primarily to meet electricity demand of nearby towns for lighting in decentralized manner. With the development of high voltage transmission lines the focus in hydropower development shifted from small hydro to large hydro projects with the objective of feeding electricity into the extensive transmission and distribution (T&D) networks. Interest in SHP projects also diminished with large-scale use of diesel generating (DG) sets for decentralized power generation. However, in the absence of other alternatives of power supply, installation of SHP projects on isolated basis continued on hilly streams in the Himalayan region of the country (AHEC, 2003).

The major boost to the growth of SHP projects in the country was received after 1989 when the activities relating to formulation of policies and development of SHP projects up to 3 MW capacity were placed by the Government of India under the administrative control of the then Department of Non-Conventional Energy Sources (DNES). MNES is now responsible for promoting development of entire SHP sector for projects up to 25 MW capacity. MNES is providing fiscal and financial incentives to encourage implementation of SHP projects by the private developers and state governments. These include financial support for undertaking surveys and investigations and also for preparation of Detailed Project Reports (DPRs) for the identified sites. While capital subsidy is being given to the government funded projects, interest subsidy is being offered to private developers. The details of various incentives that were available under the Small Hydro Power Programme of the MNES during 2002-03 are summarized in Table 1 (MNES, 2003).

The growth of SHP development in the country is shown in Fig. 1. In this figure capacity addition for each calendar year and cumulative capacity for SHP projects installed in the country for the period 1994-2002 have been depicted. In the year 1999 SHP projects of about 1000 MW aggregate capacity installed in earlier years were included in the physical achievements of the MNES due to transfer of SHP projects in the capacity range of 3-25 MW to the MNES. Therefore, the cumulative capacity of SHP projects in the year 2000 stood at 1341 MW. This aspect has not been incorporated in the growth curve shown in Fig. 1.

There are about 80,000 un-electrified villages in the country and nearly 18,000 of these villages are not likely

Table 1
Details of incentives available under the small hydro programme of the Ministry of Non-Conventional Energy Sources, Government of India

Scheme	Areas	Capacity of small hydro project				
		Below 500 kW	0.5-1 MW	Above 1 MW up to 5MW	Above 5 MW up to15MW	Above 15MW up to25MW
Survey and investigation	Plain Hilly	Up to Rs. 75,000 Up to Rs. 75,000		Up to Rs. 0.1 million Up to Rs. 0.3 million	Up to Rs.0.15 million Up to Rs. 0.3 million	
Detailed project report	Plain Hilly	Up to Rs. 75,000 Up to Rs. 75,000		Up to Rs. 0.1 million Up to Rs. 0.2 million	Up to Rs. 0.15 million Up to Rs. 0.2 million	
Interest subsidy for commercial projects	Plain Hilly & NE region	5.00% 7.50%		2.50% 5.00%	2.00% 3.00%	1.50% 2.00%
Capital subsidy for Govt. sector projects	NE region and Sikkim	90% cost of the project up to Rs. 75,000 per kW	90% cost of the project up to Rs. 60,000 per kW	75% cost of the project up to Rs. 45,000/- per kW	Equipment cost+ 25% of civil work cost limited to Rs. 225 million per project	Nil
	Middle Himalayas, Ladakh, & Andaman & Nicobar	Equipment cost + 50% of civil work cost up to Rs. 45,000 per kW		Equipment cost+ 25% of civil work cost up to Rs. 30 million per MW	Equipment cost+ 25% of civil work cost limited to Rs. 150 million per project	Nil
	Notified hilly regions of other areas	Equipment cost + 50% of civil work cost up to Rs. 30,000 per kW		Equipment cost+ 25% of civil work cost up to Rs. 15 million per MW	Equipment cost+ 25% of civil work cost limited to Rs.75 million per project	Nil
Renovation and modernization of old projects		Up to Rs. 20 million per MW			Limited to Rs. 100 million per project	Nil
Development/up-gradation of water mills		Mechanical mode: Rs. 30,000 Mechanical/electrical mode: Rs. 60,000				

1 US$ = 45.80 Indian Rupees (Rs.) as on 16.9.2003.
NE—North Eastern.

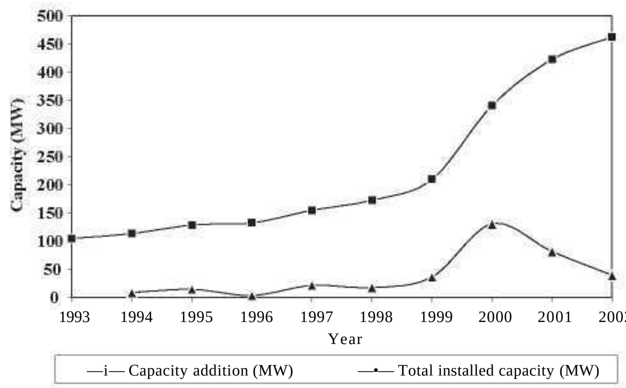

Fig. 1. Growth of SHP installed capacity in India.

to be electrified through extension of the conventional grid in near future as most of these villages are located in remote, forest, hilly, desert, islands and tribal regions of the country (MNES, 2003). All these villages are proposed to be electrified by 2007 by harnessing locally available renewable energy sources through technologies such as solar photovoltaic systems (SPV), SHP projects and biomass gasifier based power generating systems under a programme started by the MNES in 2001-02. Eleven decentralized SHP projects have been sponsored by the MNES for electrification of 80 remote villages in the states of Uttaranchal and Arunachal Pradesh under the above-mentioned programme. Twenty-four more projects are under consideration for electrification of remote villages in these states. Most of these SHP projects are up to 100 kW capacity and, therefore, fall in the category of MHP projects as per the classification of CEA.

In the past there were several technical and managerial issues related to remote MHP projects operating in decentralized mode. For example projects could not supply reliable power mainly due to problem of maintaining stable generator frequency whenever there was variation in electricity demand from the system (Paish, 2002). In addition there were problems of operation and maintenance of MHP projects at remote locations. With technological development in the area of control systems making automated operation of small power projects possible and also with appropriate systems for evacuation/utilization of power from the project sites, MHP projects have become more reliable (MNES, 2003). However, financial viability of decentralized MHP projects located in remote areas with limited electric load (mainly for lighting application and that too for limited number of hours) is yet to be established. The problem of scattered location of villages and houses in the states where these projects are being implemented, increases cost of T&D and thereby further adversely affecting financial viability of the projects. In this paper, a modest attempt has been made to examine some of the issues relating to techno-economics of some MHP projects that are being implemented or planned in the country for decentralized power supply based on the information available for these projects.

2. Analysis

Sixteen MHP projects of 10-100 kW capacity that are either being planned or under implementation in the states of Arunachal Pradesh and Uttaranchal in India have been considered for this study. The cost estimates for civil works, electro-mechanical equipment, local T&D network and for miscellaneous purposes as indicated in the DPRs for these projects have been considered in this study. For all projects up to 40 kW capacity (except S. No. 7 in Table 2) being implemented in Arunachal Pradesh, the project feasibility reports do not provide the cost estimates for T&D network separately and it is included in cost estimates for electro-mechanical equipment. In a project feasibility report prepared for another 2 x 25 kW project (with one 25 kW turbine as standby) in Arunchal Pradesh, cost of distribution lines and electrical fittings including household connections is reported to be about 37% of electro-mechanical equipment (APEDA, 2001). Considering the cost of household connections and electrical fittings as one-third of this cost, the cost of T&D network for the project works out to be about 25% of the total cost of electro-mechanical equipment. In this study, therefore, it has been assumed that the cost of T&D network for MHP projects being implemented in Arunachal Pradesh is 25% of the total cost of electro-mechanical equipment.

The levelized unit cost of electricity (UCE) delivered can be determined as the ratio of the total annualized cost to the annual electricity delivered by the system. Total annualized cost is calculated by taking into consideration the capital costs of the different main components of the MHP project (such as civil works, electro-mechanical equipment, and power house building and T&D network) and also annual operation and maintenance costs. Electricity delivered by the project has been estimated in terms of the plant load factor (PLF) of the system. The following expression has been used to estimate levelized UCE delivered to the consumer from a MHP project:

$$UCE_{„} = \frac{(R_c + m_c)C_c + (R_e + m_e)C_e + (R_t + m_t)C_t + R_bC_b + m_oC_{pww}}{8760(P)(PLF)}, \qquad (1)$$

where R_b, R_c, R_e and R_t are the capital recovery factors for power house building, civil works, electro-mechanical equipment and T&D network respectively. C_b, C_c, C_e, C_{pw} and C_t are costs of power house building, civil

Table 2
Cost details of MHP projects

S. No	Name of MHP project	Rated capacity of the project (kW)	Total capital cost of the project including T&D network (Rs.)	Cost of civil works (Rs.)	Cost of electro-mechanical equipment (Rs.)	Miscellaneous cost (Rs.)	Cost of T&D network (Rs.)	Cost per unit of rated capacity without T&D network (Rs./kW)	Cost per unit of rated capacity with T&D network (Rs./kW)
(A) *Arunachal Pradesh*									
1	Eya	10 (1 x 10)	1,520,000	450,000	480,000	395,000	520,000	120,000	1,520,000
2	Kibung	15 (1 x 15)	2,158,000	847,000	720,000	411,000	0847,000	131,867	131,867
3	Poyom	20 (1 x 20)	2,797,000	1,038,000	8,0001,000	509,000	0509,000	127,350	139,850
4	Kayi	25 (1 x 25)	3,268,000	1,225,000	1,120,000	268,000	225,000	119,520	130,720
5	Nikte	30 (2x15)	4,195,800	1,312,500	12,5001,50	783,300	375,000	127,360	139,860
6	Siki	40 (2 x 20)	5,266,000	1,875,000	1,875,000	766,000	5,000	119,150	131,650
(B) *Uttaranchal*									
7	Dokti Gaon	20 (1 x 20)	4,319,525	1,220,000	785,000	335,535	1,727,000	129,627	215,977
8	Lamchula	50 (2 x 25)	9,842,000	3,054,000	1,573,000	54,00	4,442,000	108,000	196,840
9	Rotan	50 (2 x 25)	9,562,000	2,684,000	1,573,000	573,000	4,562,000	473,000	191,240
10	Wan	50 (2 x 25)	10,389,000	2,608,000	1,600,0	97,00020	5,539,000	07,780	207,780
11	Karmi II	50 (2 x 25)	10,054,101	2,176,891	4,182,750	622,430	2,818,800	182,7506	00144,7062
12	Ratmoli	50 (2 x 25)	11,666,729	3,851,628	4,182,750	762,071	2,602,800	181,279	233,335
13	Ghes	100 (2 x 50)	12,852,000	4,081,000	3,256,000	893,000	4,352,000	852,000	128,520
14	Tarula	100 (2 x 50)	13,265,000	4,054,000	3,131,000	4,054,000	4,765,000	85,000	004,765,0
15	Bank	100 (2 x 50)	12,431,000	3,712,000	3,228,000	790,000	4,431,000	90,000	12,0
16	Kanol Gad	100 (2 x 50)	19,761,862	9,263,684	7,107,750	920,448	2,106,000	176,559	107,7509

1 US$ = 45.80 Indian Rupees (Rs.) as on 16.9.2003.

works, electro-mechanical equipment, MHP project's total cost excluding T&D network and cost of T&D network respectively. m_c, m_e, m_t and m_o are maintenance costs of civil works, electro-mechanical equipment, T&D network and operation cost of the MHP project respectively as fractions of the capital cost of the respective components. P and PLF are rated power output and PLF of the MHP projects. For a given discount rate (d) and useful lifetime (T) the capital recovery factor (R) is defined as

$$R = \frac{d(1+d)^T}{(1+d)^T - 1}. \quad (2)$$

The discounted pay back period (DPP) of an investment in an MHP project has been determined using the following expression (Kandpal and Garg, 2003):

$$DPP = \frac{\ln(B_i - C_t) - \ln[(B_i - C_t) - dC_0]}{\ln(1+d)}, \quad (3)$$

where B_i represents the annual benefit accrued to the investor by way of saving on electricity bought from an alternative option (which in this study has been considered as a DG set of the same capacity as that of the MHP project), C_i represents the annual cost of operation and maintenance of the MHP project and C_o represents the total project cost of the MHP project. B_i can be estimated as

$$B_i = 8760(p_e)(P)(PLF), \quad (4)$$

where p_e is price of electricity bought from an alternative option. Similarly, C_i is estimated as

$$C_i = m_o C_{pw} + m_c C_c + m_e C_e + m_t C_t. \quad (5)$$

The net annual monetary benefit accrued to the investor $(B_i - C_i)$ is assumed to be uniform over the useful life of the MHP project.

Net present value (NPV) of the MHP project has been determined using the following expression:

$$NPV = \sum_{i}^{T} \frac{(B_i - C_i)}{(1+d)^i} - C_0. \quad (6)$$

The salvage value of the MHP project at the end of its useful life has been assumed to be negligibly small in writing Eq. (6).

The following expression has been used to determine the Benefit-Cost (B/C) ratio:

$$B/C = \frac{\sum_{i=1}^{T}(B_i - C_i)/(1+d)^i}{C_o}. \quad (7)$$

The breakeven values of the important parameters such as PLF, useful life of an MHP project and UCE delivered have also been determined using Eq. (1).

3. Assumptions and input parameters

Useful lives of different components of MHP project such as civil works (comprising intake channel, tail race, misc. work, etc.); power house building; electro-mechanical equipment and T&D network have been considered as 50, 35, 35 and 25 years, respectively, (CE, 2001).

In this study cost of operation of an MHP project working in decentralized mode has been assumed as 1% of total project cost excluding T&D network. Maintenance costs for civil works, electro-mechanical equipment and T&D network, respectively, have been assumed as 1% of civil works' cost, 2% of electro-mechanical equipment's cost, and 2% of T&D network's cost (CE, 2001).

The predominant load served by the MHP projects in remote locations is for consumptive applications—essentially for lighting purpose in houses and community buildings and for streets/pathways. Other potential loads could be for powering television and radio/tape recorder sets. In hilly areas consumer may also use electricity for cooking, water heating and space heating by using simple resistive electric heaters. Some households may have electricity-operated mixers for use in the kitchen. So far as productive loads are concerned, there may be one or two grain grinding mills in the area/village. Keeping in view the duty cycle for these loads, there may be very small load during the daytime. Most of these types of MHP projects are generally operated for about 14 h from 5.00 PM to 7.00 AM in the hilly regions (CE, 2001). Therefore the PLF for these power projects is generally low. This may at the best be in the range of 30-45% (Appendix A).

In order to estimate the values of different measures of financial performance of an MHP project it is necessary to quantify the monetary worth of the electricity delivered to the users. Usually, the opportunity cost of the fuel saved by a renewable energy system is used for quantification of the monetary benefits. However, as MHP projects often deliver electricity, which was not available to the user at all, various possibilities exist for assigning a monetary value to the benefits of the MHP project as accrued to the users. These include extension of conventional grid on one side to the option of having electricity delivered through some decentralized power generation source such as DG set, biomass gasifier based system, SPV system, etc. A commonly advocated option of providing electricity to the remote villages is by extending the grid. In view of the remote and difficult type of terrain, information relating to distance of the villages from the nearest point from where grid can be possibly extended and the cost(s) involved in extension of grid are not easily available. Thus an accurate estimation of the UCE for grid extension option for these villages is not possible and hence a comparison has not been undertaken.

In a recent study, cost of delivering electricity from SPV power plants operating in decentralized mode for Indian conditions at Sagar Island (West Bengal) has been found to be Rs. 26.10/kWh for an estimated annual output of 1750 kWh from a SPV power plant of 1 kW_p capacity (Chakrabarti and Chakrabarti, 2002). As the above value of annual electrical output is much higher than that estimated for average Indian conditions (which is typically in the range of 1350-1500 kWh per annum for a 1kW_p SPV power plant), the UCE may be as high as Rs. 33.88/kWh. Such a value of UCE generation is very high compared to other decentralized options. Therefore, for estimation of monetary benefit accruing from the MHP projects, UCE generation based on SPV power plant also cannot be considered.

Another study based on November 1996 cost and performance data for a 40 kW biomass gasifier based system has reported the UCE generation at Rs. 3.31/kWh (Tripathi et al., 1997). However, this study did not include the cost of the shed required for housing gasifier-based power generating system and also the cost of T&D system. The cost of delivering electricity based on the method suggested in the this study and considering prevailing market price of gasifier based power generating system and Rs. 23.47 per litre as average cost of diesel as on 1.3.2003, has been estimated at Rs. 7.12/kWh. However, in view of the fact that the gasifier based power generating systems would need the supply of biomass feed stocks on a sustainable basis, the overall potential of biomass gasifier based power generation in the country, particularly in hilly and remote areas is rather limited. Therefore, this option has not been considered for estimation of monetary benefits accruing from the MHP project.

Considering the practical difficulties involved in estimation of the monetary benefits resulting from the MHP projects based on the UCE generation and delivery from other decentralized renewable energy technologies discussed above, it has been assumed that the villages proposed to be electrified though the MHP projects could have been alternatively provided with electricity using DG sets. The cost of delivering electricity from a 50 kW capacity DG set has been estimated at Rs. 9.22/kWh based on the prevailing market prices of DG set (Appendix B). The same has been used in estimation of the monetary benefits from the MHP projects considered in this study.

4. Results and discussion

4.1. Capital cost

The cost estimates of sixteen MHP projects of 10-100 kW capacity along with the cost break up for civil works, electro-mechanical equipment and T&D network, etc. are presented in Table 2. The capital cost per unit capacity for each of these MHP projects has also been worked out (with and without T&D network) and are presented in this table. It may be noted from Table 2 that there is a substantial variation in the estimated cost of civil works for the same capacity of MHP project. This may be owing to specific nature of civil work required at each site depending on local conditions. Even the cost estimates for the electro-mechanical equipment are considerably different for the same capacity of the MHP project. For example, for the case of 50 kW capacity projects, two distinctively different ranges of cost estimates for the electro-mechanical equipment can be noted in Table 2. One of the primary reasons for such a large difference in cost estimates is due to the possibility of procuring equipment from local as well as from foreign suppliers. The price of imported equipment can be higher or lower than that of the indigenously available equipment depending on a variety of factors such as marketing and pricing strategies, import duties, incentives for export, quality of the equipment, etc. In the present case the lower estimated price of the electro-mechanical equipment for three 50 kW MHP projects (at Lamchula, Rotan and Wan) is possibly due to import of the equipment from a neighbouring country. Similar behaviour is observed for the estimated price of electro-mechanical equipment for 100 kW MHP projects.

So far as the cost of T&D network is concerned, there is a considerable variation in cost for different projects of 20, 50 and 100 kW MHP projects being implemented in Uttaranchal. It may be noted from Table 2 that in certain cases the estimated costs of T&D network for 50 kW MHP projects are more than 100 kW MHP projects. Essentially, the cost of T&D network will be largely influenced by factors such as (a) need for stepping up and then stepping down of electrical voltage due to distance between project site and load centres and its associated cost implications due to installation of transformers required for these purposes, (b) number of villages to be benefited by the project and distance between these villages, and (c) dispersed or closely packed nature of households within the village and thereby influencing distance of low tension (LT) distribution lines. These factors explain the vast difference in the estimated cost of T&D network for two 20 kW MHP projects referred in Table 2. In the case of 20 kW MHP project at Poyom in Arunachal Pradesh (S.No. 3 in Table 2) only one village, located in the vicinity of the MHP project site, is to be provided electricity. Thus, LT T&D lines may be sufficient in this case. On the other hand, for the 20 kW MHP project at Dokti Gaon in Uttaranchal (S.No. 7 in Table 2), three villages are to be electrified, which are located at appreciable distances from the project site necessitating the use of step up and step down transformers and 11 kV transmission lines besides the LT lines.

The relative contribution of different sub-components of the MHP projects to the capital cost is presented in Fig. 2 for six different capacity ratings. Notwithstanding the cost variations due to site specific and market related factors explained above, the following two broad trends emerge from this figure:

(i) Cost of civil works and electro-mechanical system in terms of the percentage of the capital cost is quite significant for the smaller capacity MHP projects up to 25 kW.
(ii) Cost of T&D systems in hilly and isolated locations is highly dependent on geographical terrain, distances of villages from the MHP project, distances between the villages and dispersal of households in a village. It may therefore, vary considerably from project to project.

Estimates for the installed costs of mini hydropower electrification projects around the globe were in the range of $2500-3000/kW for larger schemes during the year 2002. At the smaller end of the spectrum (o 500 kW capacity), the cost varied widely depending on the site and country involved, and exceeded $10,000/kW. However, costs may be reduced by using indigenous expertise and technology (if available) such that costs below $1000/kW can be achieved (Paish, 2002). The range of total plant cost of MHP projects in Nepal and Pakistan was more than 2000 US$ per kW during 2000 (Rijal, 2000). Cost per kW of MHP projects for electricity supply including transmission implemented in Sri Lanka, Nepal, Peru and Zimbabwe was found to be in the range of $1136-$5630 (US$1998) (Khennas and Barnett, 2000). The cost for the MHP projects in India for decentralized power supply for villages situated in remote and inaccessible areas is estimated to be in the range of $2670-5010 per kW including the cost of power evacuation and distribution system.

4.2. Cost per unit of rated capacity

From Table 2 it is observed that there is a wide variation in cost per unit of rated capacity both for 50 and 100 kW MHP projects. This is true irrespective of the inclusion of the cost of T&D network in the total cost. For 50 kW projects, there are two distinct categories of projects. While the cost per unit of rated capacity without cost of T&D network for one category

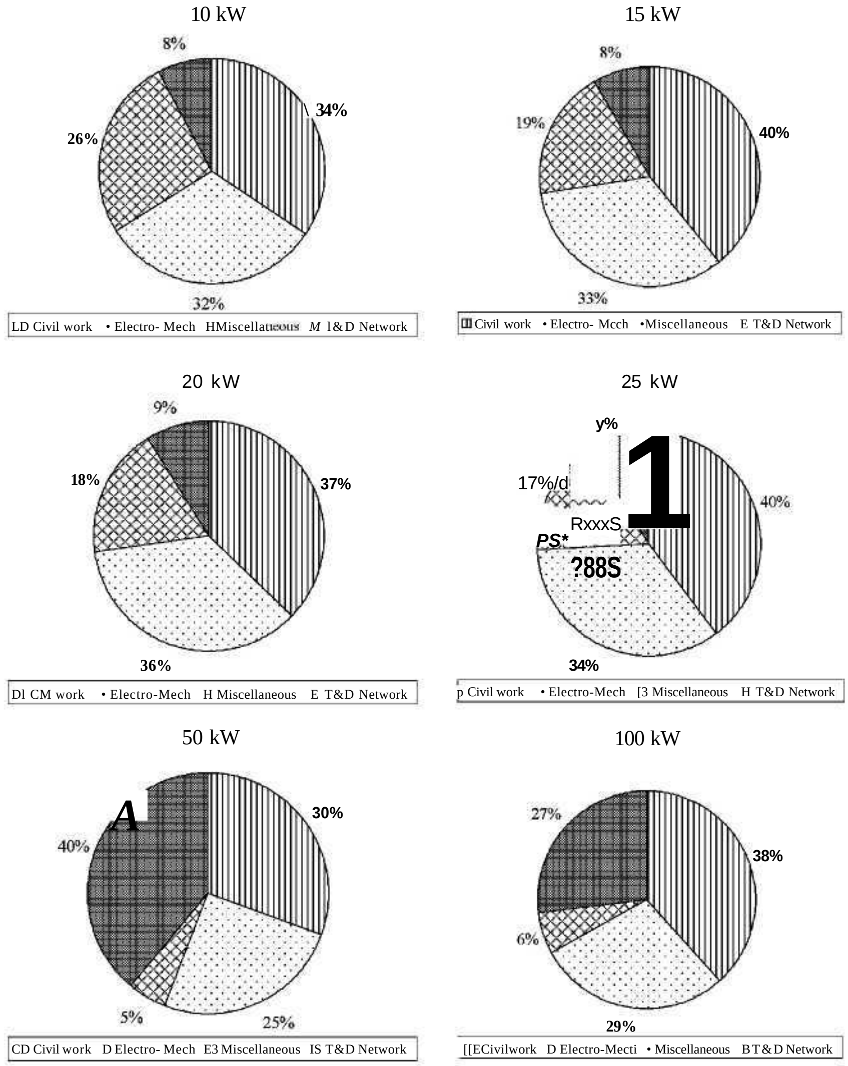

Fig. 2. Relative contribution of cost of different sub-systems of MHP projects.

of projects (S.Nos. 8-10 in Table 2) is in the range of Rs. 97,000/kW to Rs. 108,000/kW with a mean value of Rs. 101,666/kW, for the other category of projects (S.Nos. 11 and 12 in Table 2) it is in the range of Rs. 144,706/kW to Rs. 181, 279/kW with a mean vale of Rs. 162,993/kW. Similarly for 100 kW projects also there are two distinct categories of projects. While the cost per unit of rated capacity without cost of T&D network for one category of the projects (S.Nos. 13-15 in Table 2) is in the range of Rs. 80,000/kW to Rs. 85,000/kW with a mean value of Rs. 82,500/kW, for the other category of project (S.No. 16 in Table 2) it is Rs. 176,559/kW. The cost per unit rated capacity without T&D network for MHP projects of 10-40 kW capacity is in the range of Rs. 142,000/kW to Rs. 119,520/kW. This value is relatively higher as compared to the mean cost of 50 and 100 kW MHP projects. However, the cost per unit rated capacity with T&D network for MHP projects in 10 to 40 kW capacity range is comparatively lower as compared to 50 and 100 kW in view of relatively lower cost required in setting up T&D network for these plants. As expected, on including the cost of T&D network, the cost per unit rated capacity of MHP project increases substantially. The contribution of the T&D network's cost to the cost per unit rated capacity increases substantially for higher capacity MHP projects in remote locations for reasons explained earlier.

In case of 50 and 100 kW projects electricity is generated at 415 Volts (V) and is then stepped up to 11 kilovolts (kV) for the purpose of transmission to reduce losses. The voltage is stepped down to 415 V near the load centres. This calls for installation of step up (415V/11kV) and step down (11kV/415V) transformers. Moreover, total length of T&D network is high in case of 50 and 100 kW MHP projects being implemented in Uttaranchal, where villages are dispersed and houses within the villages are scattered. This is not the case in Arunachal Pradesh, where relatively smaller capacity

MHP projects in the capacity range of 10^0 kW are being set up. These projects are generally expected to supply electricity to one village or at the maximum three villages, which are located close to the project site. Moreover, in these villages, households are located close to each other. Therefore, in the case of Arunachal Pradesh only LT distribution line is considered to be sufficient. Even length of the LT distribution lines for the projects implemented in Arunachal Pradesh is comparatively smaller. These factors result in lower cost of T&D network and explain lower average cost per unit of rated capacity with T&D network for MHP plants up to 40 kW capacity. Figs. 3 and 4 depict the variation of the capital cost (with and without cost of T&D network) and rated capacity of the MHP projects of 10-100 kW sizes.

The MHP plant capacities have been divided into two separate groups of 10-25 kW (for Arunachal Pradesh) and 20-100 kW (for Uttaranchal) as the impact of the cost of T&D network is quite dominant in the later case. Economy of scale is observed in both Figs. 3 and 4 pointing towards the fact that provision of hydro electricity at higher demand levels may turn out to be relatively cheaper than in the case of the plants catering to relatively smaller loads. From a comparison of Figs. 3 and 4 it may also be noted that for plant capacities of more than 20 kW the cost per unit of rated capacity increases substantially if the cost of T&D network is also included. For example, for a 50 kW project it increases from Rs. 114,256/kW to Rs. 206,055/kW. However, with an increase in the plant size the difference between the cost per unit of rated capacity with the cost of T&D network and the cost per unit rated capacity without T&D network is less pronounced.

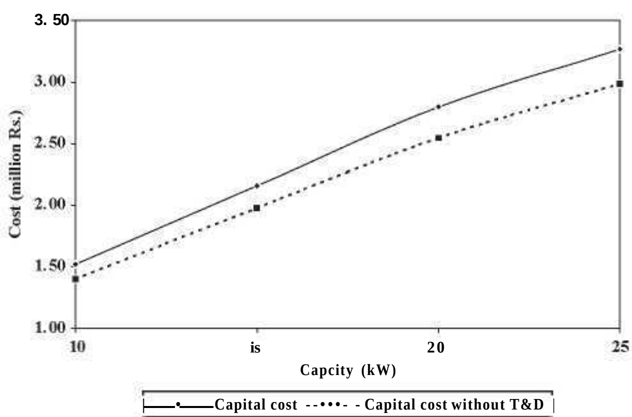

Fig. 3. Variation of capital cost of MHP projects in Arunachal Pradesh.

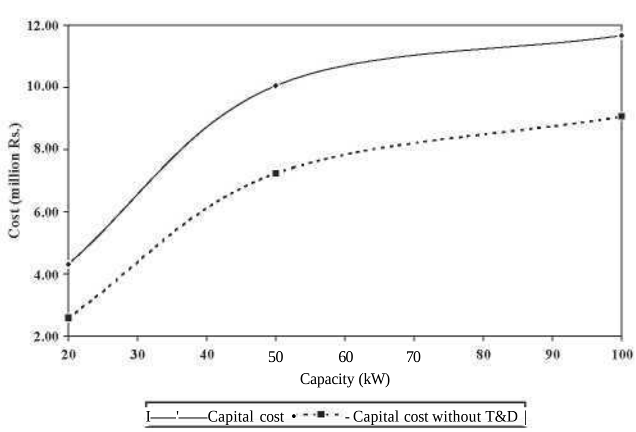

Fig. 4. Variation of capital cost of MHP projects in Uttaranchal.

4.3. Unit cost of electricity

The UCE delivered by the MHP project operating in decentralized mode can be estimated using Eq. (1). It may be noted from this equation that, for a given MHP project (with defined cost of civil works, electro-mechanical equipment and T&D network) the UCE will be very strongly influenced by the PLF. Normally the PLF would be known only after certain period of commissioning of the plant (that too if a reliable provision to collect and analyse data is ensured). A preliminary attempt based on a simple framework to estimate the most likely value of the PLF in remote rural areas has been made in the study (details presented in Appendix A). It is estimated that for such remote locations the PLF may hardly exceed 40%. Using a PLF of 40% and values of other input parameters as defined in Table 2, the UCE delivered by the MHP projects have been estimated. The variations in the unit cost of delivered electricity from MHP projects of 10-40 and 25-100 kW MHP projects being implemented in Arunachal Pradesh and Uttranchal for a PLF of 40% are shown in Figs. 5 and 6, respectively. The effect of variation in the PLF on the UCE delivered in case of the 50 kW Karmi II MHP project in Uttaranchal has also been examined and the results are shown in Fig. 7.

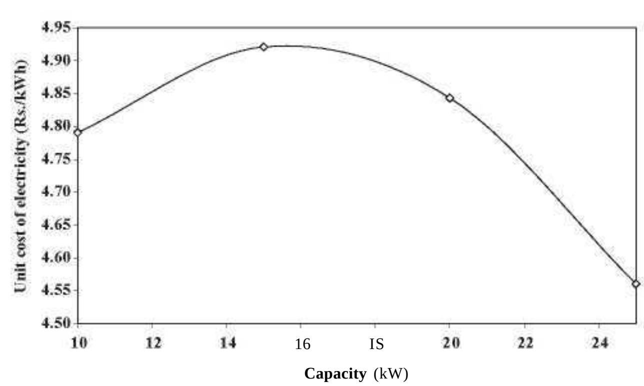

Fig. 5. UCE delivered by MHP projects in Arunachal Pradesh.

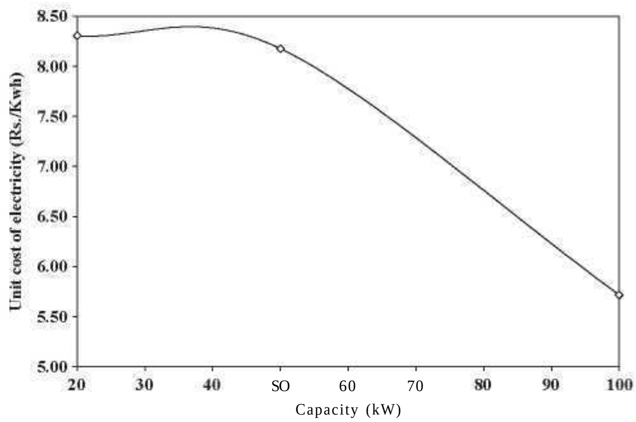

Fig. 6. UCE delivered by MHP projects in Uttaranchal.

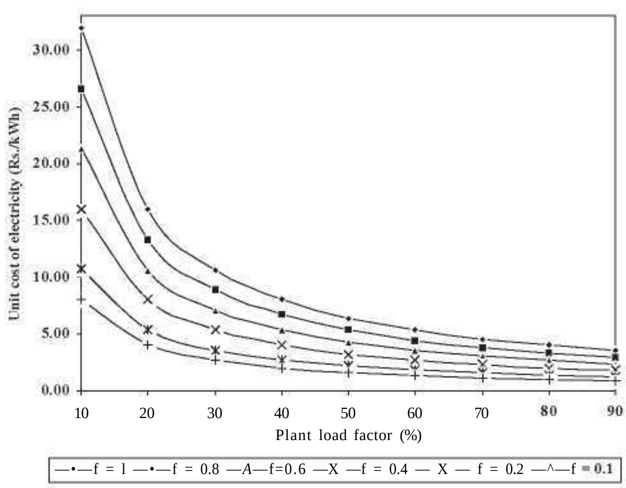

Fig. 7. Variation of levelized UCE delivered with PLF for different fractions of capital cost borne by the implementing agency for 50 kW Karmi II MHP Project in Uttaranchal.

4.4. Measures of financial performance

For 50 kW Karmi II MHP project detailed cost estimates were available. Therefore, discounted payback period (DPP), B/C ratio, NPV and the internal rate of return (IRR) for different PLF conditions have been determined for this MHP project and the values are given in Table 3. As is clear from Table 3, all financial performance measures such as DPP, B/C ratio, NPV and IRR for the Karmi II MHP project appear to be attractive only if the PLF is at least about 34.69%. As explained earlier, PLF for the MHP projects located in the remote rural areas may usually be in the range of 25^5% and, therefore, financial viability of these projects is significantly influenced by the PLF.

4.5. Breakeven analysis

The DPP is essentially the breakeven value for the useful life of the MHP project. In addition the breakeven values of unit cost electricity delivered and PLF have also been determined using Eq. (1). For the Karmi II 50 kW MHP project the breakeven value of PLF is found to be 34.69% (for an estimated useful life of 35 years of the MHP project and a price tag of Rs. 9.22/kWh for the electricity produced). The breakeven value of UCE delivered by this MHP project has been estimated at Rs. 8.00/kWh for a PLF of 40% and a useful life of 35 years. The breakeven value of useful life of the project is estimated as 15.92 years for a probable PLF of 40% and a price tag of Rs. 9.22/kWh for the electricity produced.

Table 3
Effect of PLF on the measures of financial performance for Karmi II 50 kW MHP project in Uttaranchal

PLF	DPP (years)	Benefit to cost ratio	NPV (Rs.)	IRR (%)
0.9	3.78	2.82	18,261,024	34.44
0.8	4.43	2.49	14,959,461	30.42
0.7	5.35	2.16	11,657,898	26.40
0.6	6.77	1.83	8,356,335	22.37
0.5	9.34	1.50	5,054,772	18.33
0.4	15.92	1.17	1,753,210	14.23
0.3	—	0.85	(-)1,548,353	9.98
0.2	—	0.52	(-)4,849,916	5.29
0.1	—	0.19	(-)8,151,479	—

—, not possible.

4.6. Effect of financial incentive (s) on unit cost of electricity

The MHP projects considered in this study are situated in remote and inaccessible areas. One of the main objectives of these decentralized projects is to provide access to electricity to the people of these villages, that may not have access to the grid supplied electricity in near or in some cases in distant future due to their remoteness. Majority of the inhabitants of these villages are marginal farmers and, therefore, most of them may not have adequate surplus money for purchasing electricity. They are most likely to use electricity for consumptive applications that too during the evening and early morning hours. It is, therefore, estimated that PLF for these MHP projects will be generally low and at the best about 40%. It is clear from measures of financial performance referred to Section 4.4 that a typical MHP project is not viable in case it has PLF of less than 34.69%. The breakeven value of UCE delivered as mentioned in Section 4.5 for a PLF of 40% is Rs. 8.00/kWh. The majority of the consumers may not be able to pay such a high price for electricity mainly used for lighting purpose. In order to reduce the UCE delivered to the consumers the option of providing direct financial support in the form of capital subsidy for installation of MHP projects by the Government may be considered. This will reduce the amount of capital expenditure required to be made by the local implementing agency such as a village energy cooperative or any other local body that will operate and maintain the plant after its commissioning. Depending on the fraction of the total project cost to be borne by the implementing agency, UCE delivered by a MHP project (50 kW Karmi II) will vary for different PLF as shown in Fig. 7. For a PLF of 34.69% (which is the breakeven value of PLF), UCE is in the range of Rs. 9.22/kWh to Rs. 2.31/kWh for different fractions (f) of project cost to be borne by the implementing agency as per details given in Table 4. It is seen from Table 4 that even when the project implementing agency is contributing only 10% of the project cost (assuming that the balance 90% of the

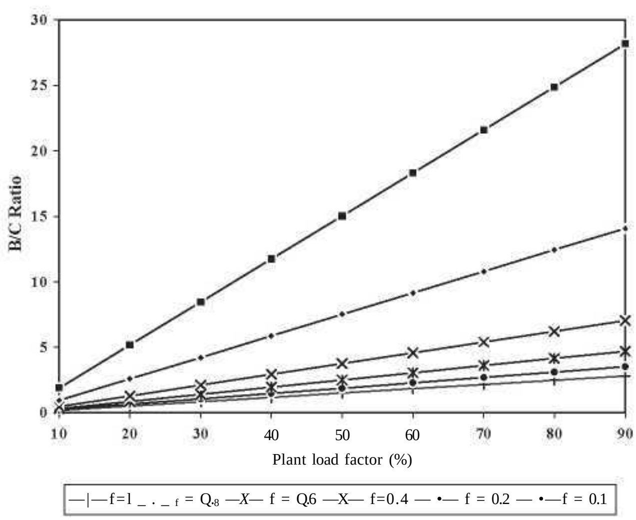

Fig. 8. Variation of B/C ratio with PLF for different fractions of capital cost borne by the implementing agency for 50 kW Karmi II MHP Project in Uttaranchal.

Table 4
UCE delivered by Karmi II 50 kW MHP project for different fractions of capital cost borne by the project implementing agency and breakeven PLF

Fraction of cost borne by the project implementer	Unit cost of delivered electricity (Rs./kWh)
1	9.22
0.9	8.44
0.8	7.67
0.7	6.91
0.6	6.14
0.5	5.37
0.4	4.61
0.3	3.84
0.2	3.07
0.1	2.31

MHP project comes in the form of capital subsidy), the UCE delivered to the consumer will be Rs. 2.31/kWh, which is more than the average price of Rs. 1.73/kWh paid by the consumer of electricity in domestic sector in 2000-01 in India (Planning Commission, Government of India, 2003). In case it is presumed that the consumer in these remote locations will also be paying a price for electricity not very different from this average price, MHP project will require financial incentive in the form of capital subsidy to an extent of at least 90% of capital cost of MHP project.

The values of the measures of financial performance considered in this study would obviously depend upon the values of the input parameters used in the calculations. It is, therefore, necessary to study the sensitivity of the results with respect to possible variations in the values of the important input parameters. Some of the results of the sensitivity analysis undertaken in the study for B/C ratio, NPV and IRR with PLF for different fractions of capital cost borne by the implementing agency for Karmi II 50 kW MHP project are shown in Figs. 8-10, respectively. The effect of discount rate on the UCE delivered from this MHP project is shown in Fig. 11.

5. Conclusions

The costs of MHP projects in India for decentralized power supply for villages situated in remote and inaccessible areas are found to vary in the range of Rs. 124,310-Rs. 233,335 per kW ($2715-5095 per kW, 1 US$ = 45.80 Indian Rupees) including the cost of power

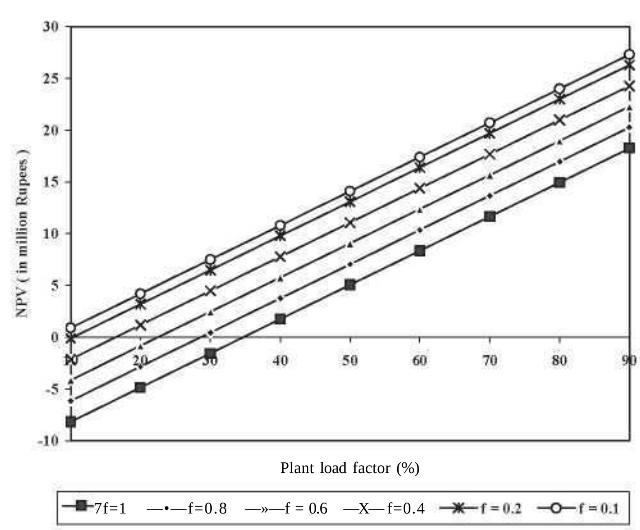

Fig. 9. Variation of NPV with PLF for different fractions of capital cost borne by the implementing agency for 50 kW Karmi II MHP Project in Uttaranchal.

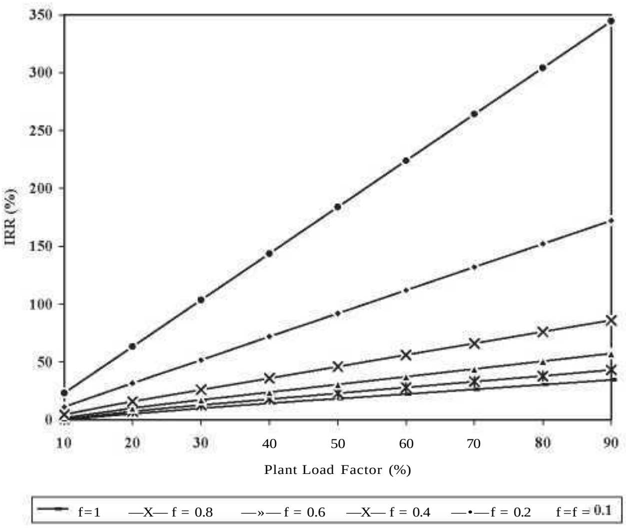

Fig. 10. Variation of IRR with PLF for different fractions of capital cost borne by the implementing agency for 50 kW Karmi II MHP Project in Uttaranchal.

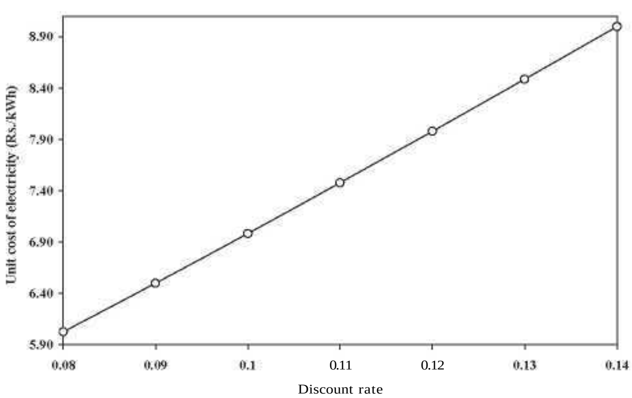

Fig. 11. Effect of discount rate on unit cost of delivering electricity for Karmi II MHP Project in Uttaranchal.

evacuation and distribution system. These values are comparable to prevailing international costs.

The capital costs of MHP projects show some economy of scale in capacity range of 10-100 kW. However, the country of origin of the equipment and site-specific features (for civil works and T&D network) have been found to substantially affect the cost figures. It may, therefore be difficult to mathematically model any such observed behaviour.

The UCE delivered by the MHP projects of up to 40 kW capacity in Arunachal Pradesh is estimated to be the range of Rs. 4.56/kWh to Rs. 4.92/kWh for a PLF of 40%. For a PLF value of 30% the UCE delivered is estimated to be in the range of Rs. 6.08/kWh to Rs. 6.56/kWh. On the other hand for MHP projects of 20-100 kW capacity implemented/being implemented in Uttaranchal the estimated UCE delivered is in the range of Rs.5.72/kWh to Rs. 8.31/kWh for a PLF of 40%. This may be attributed to higher cost of T&D network for the projects being implemented in Uttaranchal. It may be noted that even with a PLF of 30% the micro-hydro-based power option appears to be financially more attractive than the PV based option in terms of the unit cost of delivered electricity. In fact, usually it would also be a financially better option than diesel engine/ biomass-diesel dual fuel engine based alternatives. It is, therefore desirable to identify remote villages that can be benefited with MHP projects for meeting their electricity requirement.

The financial viability of the MHP projects is critically dependent on their PLF. A breakeven analysis of a MHP project indicates that the project was found to be financially unviable below a PLF of 34.69%. Integration of small scale industrial and commercial activities requiring electricity with the MHP project's development initiative would therefore go a long way in improving the financial attractiveness of these projects in remote and inaccessible areas.

In principle the UCE provided by the MHP projects analysed in this study can be competitive with the average price (Rs. 1.73/kWh) of electricity paid by the domestic sector consumers in 2000-2001, if the cost of grid extension to such remote and inaccessible areas is internalized in the unit cost of grid supplied electricity. However, it would necessitate the provision of a capital subsidy to the tune of 90% of their capital cost. Other suitable incentives and strategies may be considered for providing the requisite motivation to all the stake-holders for harnessing micro-hydropotential in remote locations.

Acknowledgement

The first author is thankful to the MNES, Government of India for granting permission and the encouragement to undertake research work in the area of decentralized power for remote areas in India.

Appendix A. Estimation of load and Plant Load Factor for Karmi II MHP project being implemented in the state of Uttaranchal

A.1. General information

Capacity of MHP project	**50 kW**
Number of villages to be electrified by the MHP project	**7**

Total numbers of households in the villages	168
Operating hours of the MHP plant	5 PM to 7 AM
Losses in local distribution system	5%

Table A.1
Estimated load connected to a MHP project in Uttranchal

Type of load	Number	Wattage of one load of its type
Domestic		
Number of incandescent lamps per household	3	40
Households having television in rural areas[a]	53	200
Households having radio in rural areas[a]	59	5
Households having electric iron[b]	8	750
Households having resistive heater for cooking[b]	8	1000
Households having resistive water heating system[b]	8	1000
Households having kitchen mixer[b]	8	750
Community		
Number of street lights[c]	84	40
Industrial		
Grain grinder	1	5000

[a]Based on 31.6% and 35.1% households owning televisions and radio sets in rural areas as per 2001 census data for India.
[b]Assuming 5% of households will have these amenities.
[c]For every two households one street light has been considered.

A.2. Assumption of load

In a typical rural household, there may be three lighting points (Living cum bed room, kitchen and toilet/bathroom). Some households with relatively higher disposable income may have other loads such as televisions, radios, electric irons and kitchen mixers. Some of the households may also have resistive electric heaters for cooking and water heating as households generally use firewood for cooking and water heating in this part of the country. Households are generally scattered in the village and street light for illuminating pathways will be preferred by the villagers. Villagers are dependent on agriculture for their livelihood and there may not be any industrial or commercial establishment in the villages except for a grain grinder, locally known as 'Gharat' in Uttaranchal, which is a mechanical system usually set up near a perennial water stream. With electricity available from MHP project, a small electrically operated grain grinder cum oil mill can be set up near the village. Based on the above assumptions, numbers and wattage of typical domestic, community and industrial loads connected to the MHP project are given in Table A.1.

A.3. Assumptions regarding daily average connected loads and peak load of MHP project during its operation

Based on certain assumptions regarding typical loads in the village that may be connected to the MHP project and their operating hours (as presented in Table A.2), the time variation of the peak load during operating hours of the MHP project during a day is presented in Table A.2.

Table A.2
Time variation of the peak load of a typical MHP project in Uttaranchal

Time of operation of the MHP project (h)	Likely number of loads considered to be in operation							Estimated peak load (kW)
	Domestic lights per household	Television	Radio	Resistive heater for cooking	Resistive heater for water heating	Street lights	Grain grinder	
17-18	1	—	59	—	—	—	1	20.8
18-19	3	53	59	8	—	84	1	47.8
19-20	3	53	59	8	—	84	1	47.8
20-21	3	53	59	—	—	84	1	39.4
21-22	3	53	59	—	8	84	1	47.8
22-23	2	53	59	—	—	84	1	27.7
23-24	1	—	—	—	—	84	—	10.1
24-1	1	—	—	—	—	84	—	10.1
1-2	1	—	—	—	—	84	—	10.1
2-3	1	—	—	—	—	84	—	10.1
3^1	1	—	—	—	—	84	—	10.1
4-5	1	—	—	—	—	84	—	10.1
5-6	2	—	—	—	8	84	—	25.2
6-7	1	—	59	—	8	—	—	23.8

Table A. 3
Estimated PLF for a typical MHP project in Uttaranchal

% of peak load connected to the MHP project	Estimated plant load factor (%)
90	46.1
80	41.0
70	35.9
60	30.8
50	25.6

A.4. Estimation of PLF

In actual practice the estimated peak load for different hours of operation of the MHP project as presented in Table A.2 may not be switched on fully for operation due to practical considerations. Therefore, the actual load connected to the MHP project will in fact be lower. PLF of the MHP power project has been estimated considering situations where only 90-50% of the estimated peak loads are switched on for operation. The results are given in Table A.3.

Appendix B. Estimation of cost of electricity delivered by a $50kW_e$ diesel generating (DG) set

The general information relating to a typical $50\,kW_e$ DG set along with the base values of different parameters relating to operation, maintenance and useful life of DG set for estimating UCE delivered by it are given in Table B.1. The following expression is used for estimation of UCE delivered by the DG set:

$$UCE_{dg} = \frac{[C_{dg}(R_{dg} + m_{dg}) + C_s(R_s + m_s) + C_{dn}(R_{dn} + m_{dn}) + 8760\,CUF(m_o + p_d s_d P)]}{(8760\,CUF\,P)}.$$

For the base value of input parameters defined in Table B. 1 the UCE delivered by DG set is estimated at Rs. 9.22/kWh.

Table B.1
General information relating to a typical $50kW_e$ DG set and base values of different parameters used for estimation of UCE

Symbol	Item	Value
C_{dg}	Installed cost DG set (Rs)[a]	440,000
C_{dn}	Cost of distribution system (Rs)[b]	250,000
C_s	Cost of shed for DG set and other items (Rs)[b]	210,000
CUF	Capacity utilization factor for DG set (fraction)	0.30
d	Discount rate (fraction)	0.12
m_{dg}	Cost of repair and maintenance of DG set as a fraction of its cost	0.1
m_{dn}	Cost of repair and maintenance of distribution network as a fraction of its cost	0.03
m_o	Cost of manpower for operation of DG set (Rs./man-hour)	10
m_s	Cost of repair and maintenance of shed as a fraction of its cost	0.02
p_d	Price of diesel (Rs./litre)	23.47
P	Capacity of DG set (kW_e)	50
R_{dg}	Capital recovery factor for DG set	0.2076
R_{dn}	Capital recovery factor for distribution network	0.1338
R_s	Capital recovery factor for shed	0.1338
s_d	Specific diesel consumption of the DG set (litres/kWh)	0.33
T_{dg}	Useful life of DG set (working hours)	20,000
T_{dn}	Useful life of distribution network (years)	20
T_s	Useful life of shed (years)	20

[a]Based on an offer received by Society for Rural Industrialization, Ranchi from M/s Ankur Scientific Energy Technologies Pvt. Ltd., Baroda in February, 2002.

[b]Based on the cost estimates for distribution system for $50kW_e$ capacity system implemented in Arunachal Pradesh in 2002.

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