A comparative life cycle energy cost analysis of photovoltaic and fuel generator for load shedding application

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Abstract

Comparative life cycle energy cost analysis for different electricity generators (photovoltaic generator, kerosene generator and diesel generator) used during load shedding is presented. The parameters considered for calculation of the unit cost of energy are: the discount rate, inflation rate, IREDA loan facility to promote PV, operation and maintenance cost of PV and fuel generator (FG) set and the associated fuel cost. It is found that the unit cost of PV electricity is comparable to or less than that of FG generated electricity at present market prices.

Keywords: Photovoltaics generator; Fuel generator; Load shedding; Life-cycle cost

1. Introduction

Load shedding in most developing countries including India due to power shortage and faults is a recurring problem and there are no remedies available in the near future. This has led to rapid proliferation of fuel generator (FG) and inverter-cum-battery system in India, which is very much alarming in view of the pollution it creates. The excessive use of FG is adding to the environmental pollution and the excessive use of inverters causes a poor power quality and availability of the grid electricity. Commercially available inverter-cum-battery system used during load shedding increases the load on an already overloaded grid. The overloaded grid has its

Nomenclature

CRF	capital recovery factor
DG	diesel generator
E_{bat}	efficiency of battery
E_{inv}	efficiency of inverter
E_{dg}	efficiency of DG
E_{kg}	efficiency of KG
$EUAW_{pvrl}$	equivalent uniform annualised worth of PV under realistic loan condition
$EUAW_{pvrl}$	equivalent uniform annualised worth of DG under minimum lending rate
FC_{pvbat}	storage battery cost
FC_{pv}	first cost or capital cost of PV
FC_{pvm}	PV module cost
FC_{pvinv}	inverter cost
FC_{pvmisc}	miscellaneous cost for PV installation
FC_{pvstr}	cost of PV structure
FC_{pvl}	cost of land for PV installation
FC_{pve}	cost of electronics, electrical and control for PV system
FLC	fuel cost
f_m	fraction of module cost (Miscellaneous cost of PV)
IRs	Indian rupees; IRs. 40 = US$ 1.00
KG	kerosene generator
LF	load factor
LH_{PY}	load shedding hours per year
LH_{PYD}	designed load shedding hours per year
LH_{PYn}	total load shedding hours for *n*th year
L_{bat}	life of battery
L_{ny}	life of *n*th subsystem in year
L_{dgh}	life of DG in hours
L_{dgy}	life of DG in years
L_{kgh}	life of KG in hours
L_{pvrst}	life of PV system without battery
OMC_{pv}	O&M cost of PV
OMC_{dg}	O&M cost of DG
PV	photovoltaic
P_{pv}	installed capacity of PV
PLD	present load demand
r_d	rate of discount
r_n	rate of inflation
r_{pv}	rate of interest of soft loan for PV (IREDA scheme)
r_r	rate of real interest

r_{ml}	minimum interest rate of commercial lending
U_{pvm}	cost of PV module per KW_p
U_{bat}	cost of battery per KWH
U_{inv}	cost of inverter per kW
UC_{grid}	cost of grid electricity per KWH
UCE_{pvlc}	life cycle unit cost of PV electricity per KWH
UCE_{dglc}	life cycle unit cost of DG electricity per KWH
UCE	cost of energy per KWH
r_{UCE}	normalised cost (UCE of PV/UCE of DG)
YAO	yearly PV array output for a particular place
IIT	Indian Institute of Technology
IREDA	Indian Renewable Energy Development Agency
MNES	Ministry of Non Conventional Energy Sources

own problems of surges, fluctuations and harmonics, etc., which reduce the life of household appliances. If these factors are considered in cost calculation, the PV energy can become comparable in cost or cheaper than the alternative electricity generators for the load shedding application [1].

Further, the efficiency of FG used during load shedding time falls drastically under variable load conditions and short duration of operation [2]. And the required installed capacity of FG is generally higher than the present load demand due to the surge problem of inductive load and possibility of increase in future load demand. The average running time of the FG for load shedding application is very minimal, however the time-dependent depreciation and operation cost need to be accounted for its unit energy generation cost. On the other hand, PV generator can be designed according to the load demand so that the capital cost of PV is fully utilised and any increase in future demand can be easily met in a modular way. Since (i) the system efficiency is not affected by the duration of operation and load demand, (ii) the system requires little operation and maintenance cost, and (iii) low interest rate is available for the system, the cost of PV electricity can become cheaper/comparable for the said application [3].

It is well established that the life cycle generation cost of PV electricity is higher than the cost of grid electricity [4–7]. But PV is cost effective as compared to FG for meeting low-energy requirement in rural/remote place [8] where the cost of carrying the fuel plays an important role. Moreover, when FG is used for load shedding application, the running time of FG is very minimal which leads to an increase in its unit cost of energy as compared to the situation when same FG operates continuously 6 or 12 h/d. However, there is no study reported so far on the comparative cost analysis of PV and FG for load shedding application. We have done first order cost comparative study [3] and have found that PV may be an economically viable alternative for load shedding application. This paper reports a detailed comparative life cycle cost analysis of FG versus PV. 400 kW DG-based emergency power generation system installed at IIT, Delhi and 1 kW-kerosene generators which have proliferated in large numbers in Delhi have been surveyed. The equivalent PV systems have been modelled for the comparative life cycle cost analysis.

2. Capital cost analysis of PV emergency power supply

The first cost of PV system (FC_{pv}) designed with specified amount of PV generation, storage and inverter capacity, can be calculated as

$$FC_{pv} = FC_{pvm} + FC_{pvbat} + FC_{pvinv} + FC_{pvmisc}. \tag{1}$$

The PV module cost depends on the power required for a specific application. The design of PV for emergency load application is based on energy replacement concept. Therefore, the installed capacity of PV (P_{pv}) can be formulated using the present load demand in kW (PLD), efficiencies of inverter (E_{inv}) and battery bank (E_{bat}), average yearly load shedding hours (LHpy) and average yearly array output in kWh per kW_p installation (YAO) at the site as

$$P_{pv} = \frac{PLD{*}LH_{py}}{YAO{*}E_{inv}{*}E_{bat}} \quad \text{and} \quad FC_{pvm} = U_{pvm}{*}P_{pv}. \tag{2}$$

The battery cost depends on the required energy storage for a certain application. The storage capacity (P_{pvbat}) has to be considered according to the load shedding pattern of a site. However, energy storage for 6 h load shedding is considered in the present study.

$$P_{pvbat} = 6PLD \quad \text{and} \quad FC_{pvbat} = U_{bat}P_{pvbat}. \tag{3}$$

The inverter cost has been calculated by considering the power rating of inverter, which is equal to the present load demand (PLD), as

$$FC_{pvinv} = U_{inv}P_{pvinv}. \tag{4}$$

The inverter cost is lower for increased power rating. However, we have considered a linear increase in inverter cost, keeping in mind the possibility of stepwise expansion with increase in load demand and decentralised generation facility. This will be more beneficial as compared to the reduction in cost with a higher wattage inverter.

The miscellaneous cost, which includes the costs of structure (FC_{pvstr}), land (FC_{pvl}), wiring, control and electronics (FC_{pve}), is given as

$$FC_{pvmisc} = FC_{pvstr} + FC_{pvl} + FC_{pve} = U_{pvmisc}P_{pv}, \tag{5}$$

where U_{pvmisc} is the unit cost of miscellaneous items. Generally the miscellaneous cost would be a fraction (f_m) of the module cost. Then

$$FC_{pvmisc} = f_m FC_{pvm}. \tag{6}$$

3. Life cycle unit cost analysis of PV

The life cycle cost analysis is based on all kinds of costs involved within an active life of the system. This cost is then converted to the present worth and averaged for annual recovery factor. Using this analysis the unit cost of PV can be calculated as

$$\mathrm{UCE_{pvlc}} = \frac{\sum \mathrm{FC}_n * \mathrm{CRF}_n + \mathrm{OMC_{pv}}}{\mathrm{PLD} * \mathrm{LH_{py}}}, \tag{7}$$

where FC_n and CRF_n are the first cost and capital recovery factor of nth subsystem of PV and $\mathrm{OMC_{pv}}$ is the annual operation & maintenance (O&M) cost of PV. The reported annual O&M cost of PV varies from 0.5% to 2.4% of the first cost. Here, we consider the reasonable annual O&M cost of PV as 2% of its first cost.

The standard formula of capital recovery factor is

$$\mathrm{CRF}_n = \frac{r_r}{1 - (1 + r_r)^{-\mathrm{L}ny}} \quad \text{and} \quad r_r = \frac{r_\mathrm{d} - r_\mathrm{in}}{1 + r_\mathrm{in}}, \tag{8}$$

where L_{ny} is the active life of nth subsystem in year and r_r, r_d and r_in are the rate of real interest, discount and inflation, respectively. The discount rate choice depends on political factor [8] and has a significant impact on unit cost calculation. We consider a discount rate of 10% for the present study.

4. Life cycle unit cost analysis of FG

Assuming that there is no wages hike in operation cost and there is also no escalation of the fuel price, the life cycle unit cost of FG can be calculated using the following equation:

$$\mathrm{UCE_{dglc}} = \frac{\sum \mathrm{FC}_n * \mathrm{CRF}_n + \mathrm{OMC_{dg}} + \mathrm{FLC}}{\mathrm{PLD} * \mathrm{LH_{py}}}. \tag{9}$$

Usually, the life of FG is considered in terms of working hours, but the calculation for capital recovery factor requires the life of FG in terms of years. When FG sets are used for emergency load application, the operation hours per year are limited. It is, however, not justified to consider the life of FG in terms of only working hours since the depreciation of FG life is supposed to be time-dependent. For example: the life of 1500 rpm DG under optimum maintenance level is 10,000 h and if load shedding per year for a particular place is 100 h, then the life of DG is 100 yr which is not at all realistic. Therefore, we consider a simplistic estimation of the life of DG in terms of year as

$$L_\mathrm{dgy} = \mathrm{Min}\{20, L_\mathrm{dgh}/\mathrm{LHpy}\}. \tag{10}$$

5. Unit cost analysis for realistic conditions by EUAW

The lower life cycle cost of PV for urban emergency application makes PV very much promising to replace the alternatives used now. But the market acceptability will be poor because the life cycle cost of PV involves an operational life of 25 yr and a high initial cost. Therefore, we also verify the cost effectiveness of PV by a cost analysis for a period of 10 yr under soft loan facility for PV.

There is a scheme to promote PV applications through financial assistance from Indian renewable energy development agency (IREDA) [9]. The guideline of the scheme is that 85% of the project finance can be available with the interest rate of r_{pv}, moratorium of 2 yr and pay back time of 10 yr for urban PV power generation, with the PV modules contributing to 50% of the cost. Therefore, we assume an equivalent loan scheme for DG for 10 yr with 10 instalments and minimum lending rate of interest (r_{ml}) and compare the unit cost energy of PV and DG. Under these assumptions, after 10 yr the PV energy will be available almost free of cost and the DG energy will be dependent only on fuel cost.

The designing of PV for emergency application is very much different from other application, but the maximum soft loan available is 85% of the project cost. Therefore, we consider two different lending mechanisms for the first cost of PV and consequently two terms and condition, such as moratorium time and rate of interest. Following these, the instalments of PV loan can be calculated when balance of system cost is less or equal to the PV module cost as

$$I_{pv} = I_{pv8} + I_{pv10} = 0.85FC_{pv}(1 + 10r_{pv})/8 + 0.15FC_{pv}(1 + 10r_{ml})/10. \quad (11)$$

The ratio of the balance of system cost and PV module cost depends on the values of the LHpy and other design parameters for a specific application. Therefore, the balance of system cost may exceed the PV module cost. In such a case, the extra cost for the balance of system will be considered as commercial loan. Then the instalments of PV loan will be given as

$$I_{pv} = I_{pv8} + I_{pv10} = 1.7FC_{pvm}(1 + 10r_{pv})/8 + (FC_{pv} - 1.7FC_{pvm})(1 + 10r_{ml})/10. \quad (12)$$

Suppose the present worth of money is W_{pv} for the instalments of I_{pv} of nth year, then

$$W_{pv} = I_{pv}/(1 + r_{in})^n. \quad (13)$$

Then the annualised present worth of total payment will be as follows:

$$\begin{aligned} W_{pvt} &= I_{pv10}\{1/(1 + r_{in}) + 1/(1 + r_{in})^2 + , \cdots, + 1/(1 + r_{in})^{10}\} \\ &\quad + I_{pv8}\{1/(1 + r_{in})^3 + 1/(1 + r_{in})^4 + , \cdots, + 1/(1 + r_{in})^{10}\} \\ &= I_{pv10}\frac{1 - (1 + r_{in})^{-10}}{r_{in}} + I_{pv8}\frac{(1 + r_{in})^{-2} - (1 + r_{in})^{-10}}{r_{in}}. \quad (14) \end{aligned}$$

Therefore, we can calculate EUAW (W_{EUAWpv}) for total payment towards only the initial investment on PV as

$$\mathrm{EUAW}_{\mathrm{pvrl}} = W_{\mathrm{pvt}}/10. \tag{15}$$

Now the total load shedding hours of the nth year (LHpy_n) may be either more or less or equal to the designed yearly load shedding hours (LHpy_d). $\mathrm{LHpy}_n = \mathrm{LHpy}_d$, there is no problem in the supply meeting demand. If $\mathrm{LHpy}_n > \mathrm{LHpy}_d$, then more energy is required to meet emergency power demand for total hours of load shedding of the nth year. The shortfall in energy can be met by charging the batteries using either smaller DG set or grid. For simplicity, the charging of the batteries using grid has been considered. The cost of this energy has been taken to be the unit cost of grid electricity ($\mathrm{UC}_{\mathrm{grid}}$) and is added to the total cost of PV energy. Similarly when $\mathrm{LHpy}_n < \mathrm{LHpy}_d$, then excess PV energy produced is considered to be sold to grid at the same cost. Then the 10 yr average unit cost of PV emergency power generation at the present worth can be formulated for the nth year as

$$(\mathrm{UC}_{\mathrm{pvrl}})_n = \frac{\mathrm{EUAW}_{\mathrm{pvrl}} + \mathrm{OMC}_{\mathrm{pv}} + \mathrm{TLC}*\mathrm{LF}*\mathrm{UC}_{\mathrm{grid}}*(\mathrm{LH}_{\mathrm{py}n} - \mathrm{LH}_{\mathrm{pyd}})}{\mathrm{PLD}*\mathrm{LH}_{\mathrm{py}n}}. \tag{16}$$

Similarly, the 10 yr average unit cost of DG in terms present worth can be calculated by EUAW of initial investment of DG for nth year as

$$(\mathrm{UC}_{\mathrm{dgrl}})_n = \frac{\mathrm{EUAW}_{\mathrm{dgrl}} + \mathrm{OMC}_{\mathrm{dg}} + \mathrm{FLC}}{\mathrm{PLD}*\mathrm{LH}_{\mathrm{py}n}}. \tag{17}$$

and

$$\begin{aligned}\mathrm{EUAW}_{\mathrm{dgrl}} &= W_{\mathrm{dgt}}/10 \\ &= \mathrm{FC}_{\mathrm{dg}}(1 + 10r_{\mathrm{ml}})\{1/(1 + r_{\mathrm{in}}) + 1/(1 + r_{\mathrm{in}})^2 \\ &+ \cdots + 1/(1 + r_{\mathrm{in}})^{10}\}/(100r_{\mathrm{in}}) \\ &= \mathrm{FC}_{\mathrm{dg}}(1 + 10r_{\mathrm{ml}})\frac{1 - (1 + r_{\mathrm{in}})^{-10}}{100r_{\mathrm{in}}}.\end{aligned} \tag{18}$$

6. Case study

In order to obtain a realistic cost comparison between PV and FG emergency power generation, a survey has been conducted on 1 kW kerosene generator (KG) sets and 400 kW diesel generator (DG) sets. The 1 kW KG sets are very widely used during load shedding time in Delhi and the 400 kW DG sets, installed at IIT Delhi, provide the required power demand during the load shedding hours.

The different parameters of 1 kW KG set are shown in Table 1. These KG sets are mainly privately owned and there are no reliable data available on these sets, which makes it very difficult to formulate O&M cost of these sets. There is a regular maintenance cost of FG for engine oil change after a fixed hours of operation,

Table 1
(a) Yearly (1996) of 400 kW DG sets as IIT, Delhi

Parameters	Value
Operation cost (annual wages of 12 person)	IRs. 12,00,000
Maintenance and overhauling cost	IRs. 77,000
Energy produced	37,273 kWh
Diesel consumed	15,960 l
Lubricant oil consumed	150 l
Load shedding hours	215 h

(b) Different parameters for the unit cost calculation of KG and DG sets

Parameters	Name & unit	Value
FC_{1KWKG}	First cost of 1 kW KG (IRs. $\times 10^3$)	22
$FC_{400KWDG}$	First cost of 400 kW DG, Kirloskar on 12.07.90 (IRs. $\times 10^6$)	19.75
FC_{1KWKG}	First cost of 400 kW DG, Detriot on 27.10.95 (IRs. $\times 10^6$)	25.95
E_{kg}	Efficiency of KG(kWh/1)	1.0
E_{dg}	Efficiency of DG(kWh/1)	2.22
U_{kgs}	Subsidised price of kerosene (IRs./1)	3
U_{kgr}	Real price of kerosene (IRs./1)	7
U_{dgs}	Subsidised price of diesel (IRs./1)	10
U_{dgr}	Real price of diesel (IRs./1)	12
L_{kgh}	Life of KG ($h \times 10^3$)	4.5
L_{dgh}	Life of DG ($h \times 10^3$)	7
LF	Load factor	0.41
LHpy	Average yearly load shedding time, at IIT Delhi (h)	127

cleaning, overhauling after certain interval, etc. The maintenance cost of DG increases exponentially with age(or hours of operation). The reported annual O&M cost of DG sets have been considered in different ways: (i) percentage of hardware cost, (ii) proportional to working hours, (iii) proportional to energy produced and (iv) a fixed value plus proportional to hours of operation. In this paper, the O&M cost for other generators has been considered as 2% of the hardware cost of PV and Rs. 6 per kWh produced for KG (1–10 kW).

There are two DG sets of 400 kW capacity manufactured by Kirloskar (India) and Detriot (India) at IIT Delhi. The Kirloskar set was installed on July 1990 and Detriot on October 1995. At present, the load during power outages is alternately shared between these two-DG sets. Table 1a and b shows different parameters used for cost calculation of the DG sets. It is to be noted that the cost of DG sets (IRs. 6500/kW = US$160/kW) is lower in India [8].

The load shedding patterns at IIT, Delhi from 1991 to 1996 and for different months in 1996 are shown in Figs. 1a and b. A PV-based emergency power generation model has been designed to meet the load equivalent for the 1 kW KG set and the existing DG sets in IIT, Delhi. Table 1b shows different economic parameters of PV system considered in this model.

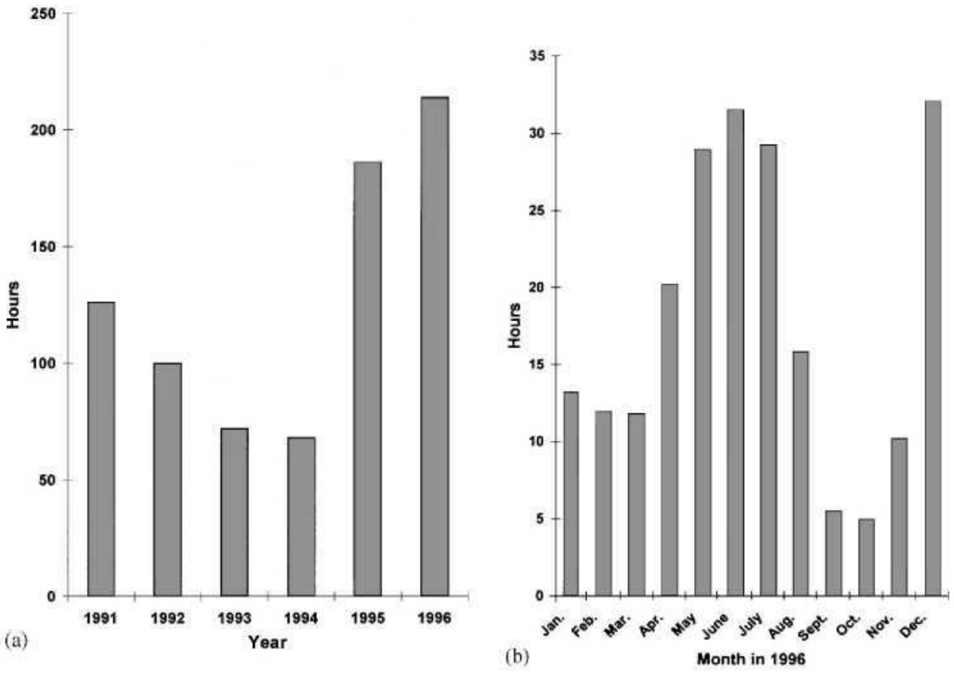

Fig. 1. Distribution of load shedding hours at IIT, Delhi for different: (a) years (1991–1996) and (b) months of 1996.

7. Discussion

The value of LHpy can be obtained from Fig. 1a and it is found to vary from 68 h to 215 h at IIT, Delhi. It should be pointed out that the all India average LHpy is about 700 h. Further, it can be seen from Fig. 1b that load shedding hours in summer months are more, with the exceptional case in December 1996 when there were major problems in the power generation and transmission. Obviously, the PV system has to be designed in such a way that the energy demand is met throughout the year. Therefore, we have used different values of designed LHpy (150 h, 300 h and 500 h) in order to meet different emergency situations.

There is virtually no maintenance or operation cost for PV system. However, the maintenance and operation cost (OMC_{pv}) is considered to be 2% of the capital cost for any incidental expenses. The land cost is not considered in this calculation because small land is required for this application and the roof area of most of the buildings can be used for this purpose. Although the general practice to consider the value of FC_{pvmisc} (without land) is 5–10% of PV module cost, the value of f_m is taken as 0.10 as shown in Table 1b.

The calculated values of life cycle unit cost of energy (UCE) for 1 kW kerosene generator and its equivalent PV generator are plotted against different LHpy in

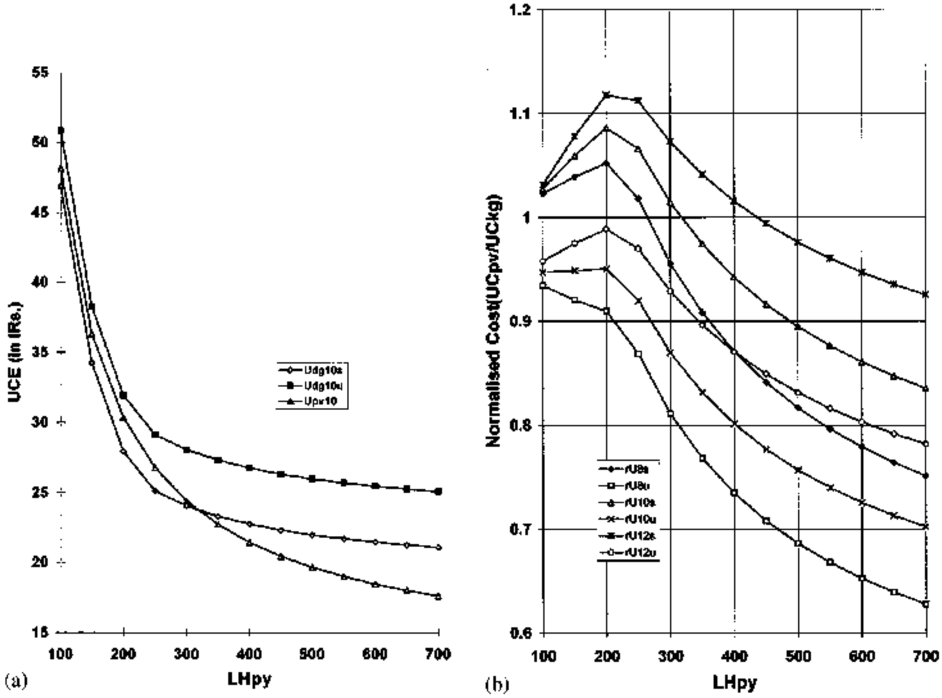

Fig. 2. UCE variation for PV and 1 kW KG with LH_{py} for: (a) subsidised and unsubsidised kerosene cost; (b) different discount rates.

Fig. 2a. The unit cost of PV energy is seen to be cheaper than the KG energy cost without subsidy cost of kerosene for a site where yearly load shedding is less than or equal to the 700 h. On the other hand, the PV energy will be costlier as compared to the KG energy if the subsidy price of kerosene (Rs. 3/l) is considered for a place where yearly load shedding less than 300 h. Beyond the LHpy of 300 h the unit cost of PV energy is again comparable or cheaper with the KG energy with subsidized cost of kerosene. It is also found from this figure that the difference of the unit cost of PV and KG is more (PV is more cost effective) for a place where the value of LHpy is high and is less than $\sim$ 20% for low LHpy. For a place like Delhi where LHpy is around 200 h, PV can thus be cost effective for emergency power generation in small establishments.

The discount rate plays an important role for the calculation of UCE. However, there is little effect of its variation, from 10% to 15%, on the comparative cost calculation of PV and KG (Fig. 2b). The normalised cost (cost of PV divided by cost of KG with subsidy) is also less than 1 for LHpy of 300 h for a discount rate of 10%, similar to Fig. 2a. It is also found that the PV energy will be significantly cheaper than the kG energy (without subsidy) for a discount rate of 12%.

The life cycle UCE of 400 kW DG and its equivalent PV generator have been calculated and are plotted in Fig. 3a. Again the PV energy is cheaper than the DG energy for LHpy < 700 h. It is found from Table 1b that the load factor of the existing system is 0.41. The load factor is low because of the technical problem associated with a DG set. The required installed capacity should be 3–5 times higher than the designed load capacity to provide for the surges generated due to inductive load. However, the PV inverters can provide 300–500% surges without any failures and the battery bank can supply the required surge current. Proper load management can further improve the load factor. Therefore, a study has been made for an increased load factor of 0.72 by keeping all other parameters fixed. Even for the load factor of 0.72 the PV energy is cheaper for LHpy below 300 h and remains comparable for LHpy value as high as 500 h.

Two-DG sets operate alternately to maintain 100% reliability for meeting the emergency load in IIT, Delhi. The capital cost of DG (C_{dg}) would be IRs. 2.6 million if one DG is installed instead of existing two sets. Keeping other parameters fixed and putting the value of C_{dg} as IRs. 2.6 million, the UCE of DG has been calculated and the normalised cost (UCE of PV/UCE of DG) is plotted in Fig. 3b. It is found to be less than 1 for LHpy below 700 h. The O&M cost per year of IRs. 1.277 million is also high. Therefore, the UCE of DG has been calculated using an O&M cost of IRs. 0.65 million which is almost half of real value of O&M cost. In this case, the normalised cost is > 1 for LHpy > 300 h but the cost difference is within 10% for higher values.

Fig. 3c shows the variation of the normalised cost for DG with different discount rates. It also shows that the PV energy will be cheaper for the discount rate of 12%. The normalised cost of 400 kW DG and its equivalent PV rises with increase of LHpy, which is opposite to the variation of the normalised cost for 1 kW KG. This is because the annual O&M cost of 1 kW KG is considered to be proportional to the energy produced whereas the annual O&M cost of 400 kW DG is assumed to be fixed.

The life cycle unit cost of PV energy is less than that of fuel generators for emergence power generation in special cases. However, because of very high initial investment and life cycle of PV, it is difficult to substitute the existing alternative generators. A more favourable situation arises if the cost calculation for PV emergency generation is done considering the soft loan facility from Indian Renewable Energy Development Agency (IREDA). The normalised cost of 400 kW DG and its equivalent PV has been plotted in Fig. 4a. The unit cost of PV is lower for LHpy < 450 h. LHpy is obviously less (300 and 250 h, respectively) if the first cost of 400 kW DG is taken as IRs. 2.6 million and the annual O&M cost as IRs. 0.65 million.

A PV emergency power generation system has been designed for yearly load shedding ($LHpy_d$) hours of 150, 300 and 500 h. The UCE of the PV system has been calculated (Fig. 4b) by considering the realistic soft loan for PV through IREDA. It is found that the PV energy is cheaper for $LHpy_d$ of 150 and 300 h as expected from Fig. 4a, but is expensive for $LHpy_d = 500$ h. This means that the capital cost of the PV system is not fully recovered even after considering the IREDA loan facility.

The pollution cost of DG, increasing trend of salary/wages and escalation of fuel price will add to the cost of DG electricity. An analysis is being made to quantify how these factors actually affect the DG electricity cost.

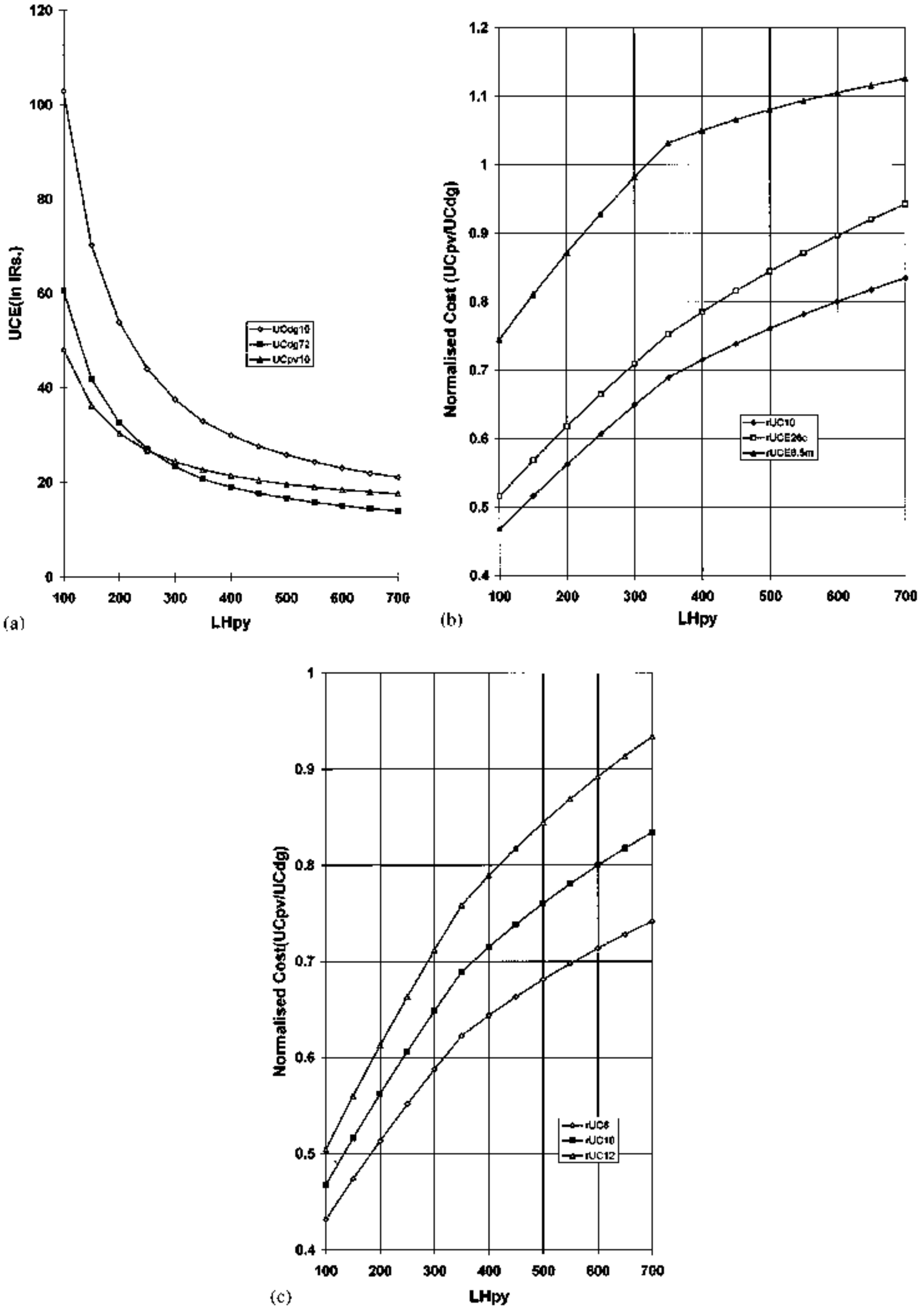

Fig. 3. (a) UCE variation for PV and 400 kW DG with LH_{py} for different LF values; (b) Variation of normalised cost for PV and 400 kW DG with LH_{py} for different DG system parameters; (c) Variation of normalised cost for PV and 400 kW DG with LH_{py} for different discount rates.

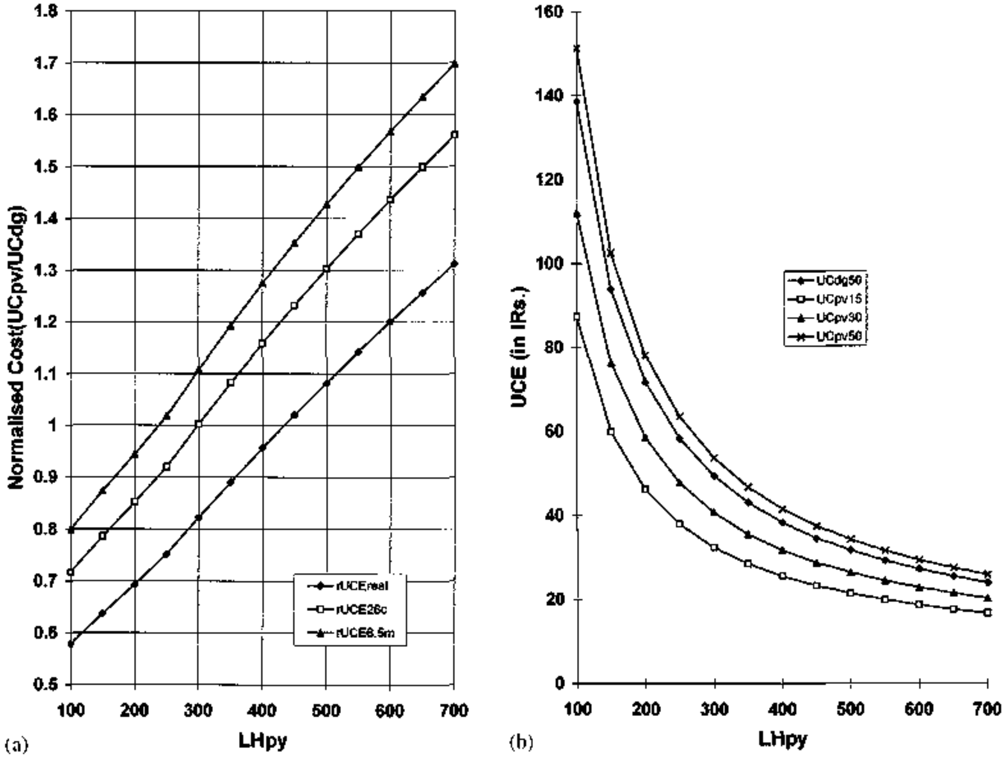

Fig. 4. (a) Variation of normalised cost for PV and 400 kW DG with LH_{py} using IREDA loan facility; (b) UCE Variation with LH_{PY} for PV system designed for different LH_{Pyd} values using IREDA loan facility.

8. Conclusion

The life cycle unit cost of PV energy is found to be cheaper or comparable to the unit cost of diesel or kerosene generator for the load shedding application. PV is cost effective in comparison with FG, even after considering a subsidy on the price of diesel and kerosene. The effect of various parameters affecting the PV system design and hence the cost has been investigated. It is found that PV remains cost effective for various situations taking advantage of short term cost benefit available from IREDA.

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References

[1] P.K. Koner, V. Dutta, K.L. Chopra, IREDA News 9 (1998) 45.
[2] G.J. Jones, R.N. Chapman, photovoltaic/diesel systems: the design process, Proceedings of 21st IEEE PV specialists Conference, 1990, pp. 1024–30.
[3] P.K. Koner, V. Dutta, An economic feasibility analysis of photovoltaics power during urban load shedding time, Sol. Energy Mater. Sol. Cells 51 (1998) 339.
[4] P.J. Reddy, Market survey on power by residential household sector in urban area, IREDA NEWS 9 (1998) 101.
[5] I. Ashraf, A. Iqbal, M.S.J. Asghar, Performance evaluation of an experimental 100 kW Kalyanpur solar photovoltaic power plant — a case study, Proceedings of IEEE International Conference on Power Electronics, Drives and Energy System (PEDES) for Industrial Growth Vol. 2 (1996) 107–113.
[6] R. Ramanathan, L.S. Ganesh, A multi-objective evaluation decentralized electricity generation options available to urban households, Ener. Conv. Mgmt. 35 (1994) 661, and J. Percebois, Ellipses (Ed.), Energie Solaire Photovoltaique: Aspects Socio-Economique, Vol. 2, 1993, p. 45, ISBN 2-7298-9390-3.
[7] W.M. Babiuch, E.C. Boes, A concept paper: alternative electricity investments and their impacts on the quality of life, Proceedings of 13th EC PV Solar Energy Conference, 1995, pp. 840–843.
[8] G. Notton, M. Muselli, P. Poggi, Costing of a stand-alone photovoltaic system, Energy 23 (1998) 289.
[9] 'Guidelines for LOAN assistance', Indian Renewable Energy Development Agency (IREDA) Limited, A Government of India Enterprise, Updated 1.1.97.