Economic and Reliability Evaluation of Hybrid Photovoltaic Energy Systems for Rural Electrification

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Received: 21.01.2019; Accepted:28.02.2019

Abstract- This paper presents economic and reliability evaluation of solar photovoltaic energy system for rural electrification. The solar photovoltaic energy system supplies energy to irrigation and farmhouse electrification. The performance of different configurations based on photovoltaic, diesel generator and battery backup in terms of technical, economical, environmental and reliability indices have been compared. Motivation behind this work is to improve living standard of rural resident using more reliable, cost-effective and sustainable rural electrification. Hybrid Optimization Model for Electric Renewable (HOMER) software is used for economic and environmental analysis. Frequency-duration method is used for reliability indices i.e. failure frequency and mean durations. The result shows that, hybrid PV/battery/diesel system is more economical, environment friendly and reliable system as compared to other configuration. This research work will help in decision making for policymakers and system designers, to determine optimal system in rural electrification before installation.

Keywords Availability, frequency-duration, life-cycle cost, reliability analysis, unavailability

1. Introduction

Energy plays a vital role in the progress and development of any country. The main priority of developing countries is to provide energy for economic development. The production, supply and use of energy are associated with the number of environmental problems e.g. release of radioactive emissions, oil spills, nuclear waste, damage ecosystem, greenhouse effect etc. [1]. Renewable energy sources (solar, wind, biomass etc.) promise clean and abundant sources of energy. Solar energy is the most prominent among them [2]. The solar PV module is the most expensive (about 60% of the total system cost) component in a solar PV system. A systematic evaluation of their economic and reliability analysis is essential [3-4].

India is a country of 638,000 villages and more than 70% of India's population is involved in agriculture. Farmers are completely dependent on rainfall and groundwater to fulfill the irrigation need of their crops. The irrigation pump sets load amounts of about 10-15% of India's total electricity demand [5]. The numbers of villages in India are located away from the existing grid and a mounting new grid is too expensive. The use of renewable energy is attractive for water pumping and lighting applications in remote areas of India. There are 21 million irrigation pumps in India out of which over 9 million run on diesel and 12 million on electricity grid [6]. The solar operated photovoltaic (PV) water pumping system provided a better sustainable alternative option to fulfill the irrigation requirement of agriculture. Reference [7] presented an economic analysis of PV only, diesel generator (DG) only and hybrid PV-DG water pumping system for irrigation. PV based pumping system reduces the net present cost (NPC) of the system as compared to DG systems. In [8] described the life cycle cost (LCC) of PV system is lower than the DG system for water pumping in remote areas. Reliability plays a vital role in the cost-effectiveness of systems. RE system optimization is based on the techno-economic analysis using HOMER software. The cost comparison in terms of levelized cost of energy (COE), NPC, operating cost (OC) and a renewable fraction. The result indicates that the hybrid PV/diesel/battery configuration is as optimum planning in remote areas [9].

Reliability of a system is assessed in terms of indices i.e. availability (A), unavailability (U), mean up time (MUT), mean downtime (MDT), system failure and repair rates. Monte Carlo simulation, fault tree analysis, and Markov process based methods have been used for reliability assessment of renewable energy systems (RES) [10]. Reference [11] minimized the capital, operation, and maintenance cost using optimized Monte-Carlo simulation scheme for a hybrid system. Monte-Carlo simulation scheme is used for a solar-wind renewable project and compare the power of both energy project [12]. Economic (NPC, COE, OC) and reliability assessment (Energy Not Served (ENS), Loss of Load Probability (LOLP)) for a hybrid wind/PV/battery generation system presented by [13]. In [14] described reliability analysis of solar PV system components e.g. PV panels, IGBT, diode, and AC subpanel of PV system using the Markov method. Failure and repair rates have been calculated using Monte-Carlo method. Complete reliability evaluation of residential PV System components e.g. PV panel, DC-DC converter, inverter and control units using a Markov model is presented in [15].

The reliability and economic feasibility of hybrid RES for rural electrification in India have been presented by Chatterjee and Rayudu [16]. Khare et al. [17] evaluated reliability of hybrid RES of a police control room Sagar, India. HOMER software has been used for the optimized assessment in terms of initial cost, installation and replacing cost. Patel and. Singal [18] developed an integrated renewable energy system (IRES) model using solar, wind and biomass sources to meet the load demand of Khatisitara village of Gujarat state in India. PSO and genetic algorithm (GA) have been used for IRES model optimization. Gangwar et al. [19] evaluated cost and reliability of a stand-alone hybrid RES (PV/wind/fuel cell/battery) for low load factor building by using HOMER software. The different combinations of PV/wind/fuel cell/battery are analysed and accounting present and futuristic growth of load demand.

Literature review shows that, many researchers evaluated RES reliability and economic assessment. Most of the studies evaluated reliability indices i.e. LOLP, ENS, components failure rate. The selection of optimization RES, considered only NPC, LCOE and ALCC economic analysis. Reliability indices i.e. unavailability, frequency rate and mean downtime have not considered in previous research for stand-alone PV only, PV/battery, PV/diesel, diesel only, diesel/battery and PV/diesel/battery configurations. These indices indicate improvement in the quality of supply system. For adequate quality of supply, threshold values of these indices may be specified based on requirement of consumer. The reliability indices evaluated using Frequency-duration (F-D) technique have not considered in the above reviewed literature. These system configurations have been evaluated based on economical as well as environmental parameters i.e. investment cost (IC), NPC, COE, total annual cost (AC).

The main objective of this research work is to find the optimum energy system configuration of the existing resources (PV, diesel and battery) at a given location that can fulfill the load demand in a reliable and cost-effective manner. To achieve this objective it is required to perform economic and reliability evaluation.

2. Methodology

The process starts with the collection of solar insolation and load demand data from the site. Next, the design of the hybrid energy system components according to the load demand. Parallel energy system components (PV, diesel generator, battery) are connected in this method. Finally, the selection criterion of the optimal energy system combination for a rural area is based on the reliability and economic analysis. Calculate different configurations LCC, compared and select the most cost-effective configuration. Reliability indices have also been calculated and more reliable energy system configuration has been selected.

3. Optimal Hybrid RES

Hybrid energy system input (solar insolation), components (PV, converter, inverter) and output (load demand) exhibits. The design and construction are complex and costly. An optimized hybrid PV energy system with a cost-effective and having acceptable reliability is required. It is required to select an optimal hybrid energy system from different system configurations based on economical and reliability parameters. The flowchart for the selection of optimum RES is shown in Fig. 1.

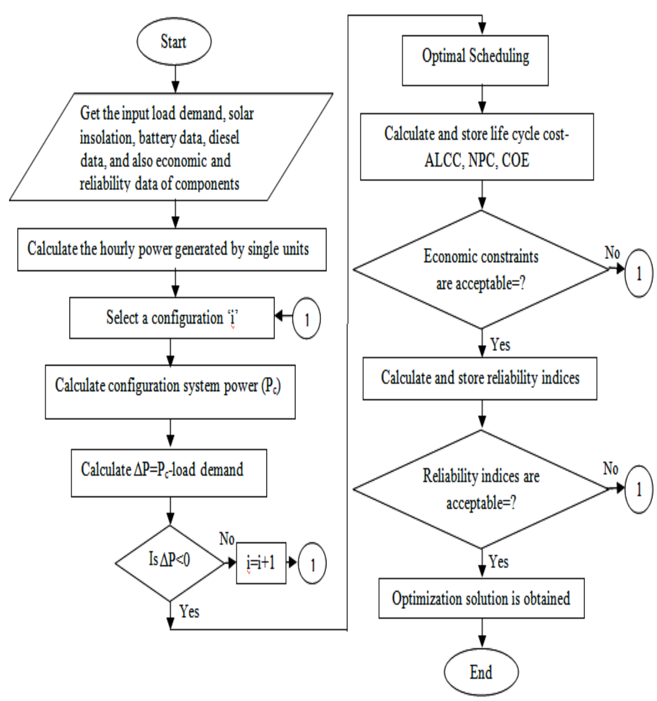

Fig. 1. Flowchart for selection of optimum RES

3.1 Solar Insolation and Load Profile in the Study Area

Figure 2 shows monthly average solar radiation and load in the case study area. The average solar insolation in case study (latitude 22.6647° N and longitude 75.8359° E) is 5.63 kWh/m^2/day [20]. Farmhouse load consists of CFL, TV, fan, refrigerator, computer etc. for lighting and motor-pump load for irrigation. The daily AC load consumption is 7 kWh/day. In the months of Nov, Dec, Jan and Feb, May, June and July average load demand is 1.8 kW while in the months of March, April, May, June, July, Aug, Sept and Oct average load demand is 1.6 kW.

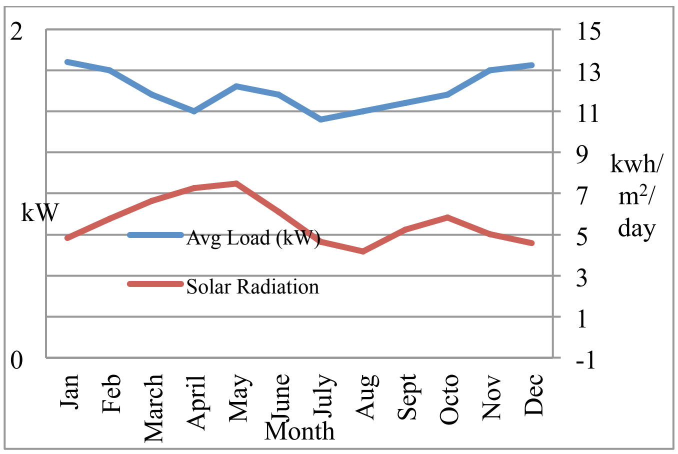

Fig. 2. Monthly average load profile and solar insolation [20]

3.2 Design of Hybrid PV Energy System

A Proposed farmhouse system model is shown in Fig. 3. Hybrid PV energy system (HPVES) has fulfilled the demand of irrigation load and lighting load of a farmhouse. Farmhouse system components consist PV generator, converter (bi-directional), inverter, battery with charge controller, diesel generator set and load.

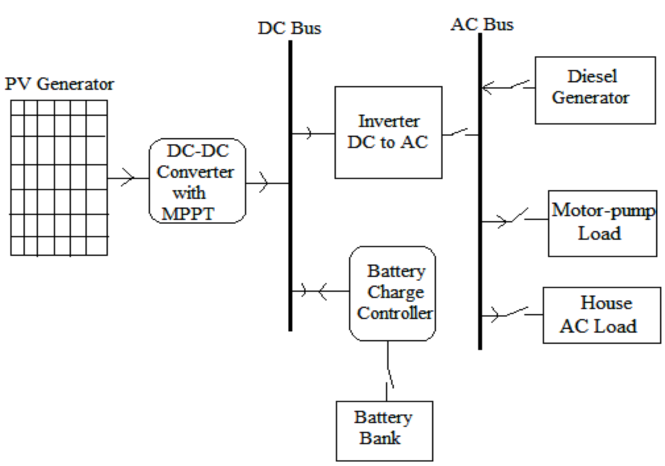

Fig. 3. Farmhouse system model

3.2.1 PV Generator

A Solar cell is a semiconductor device which converts solar radiation into direct DC electricity via the photoelectric effect. The numbers of solar cells are connected in series and are called module. The modules are connected in series or parallel and called PV array. Voltage and current of PV generator depend on the individual voltage and current of the interconnected solar modules. The PV generator output power is given as follows [21],

$$P_{pv\_op} = P_{rated} f_{pv} \frac{G_t}{G_{sc}} \times [1 + \alpha_T (T_{ct} - T_{ref})] \quad (1)$$

Where P_{pv_op} is the output power of PV generator, P_{rated} is the rated power of PV generator, f_{pv} is derating factor (%), G_t is solar irradiance (W/m^2), G_{sc} is the solar insolation under standard conditions (1kW/m^2), α_T is temperature coefficient, T_{ct} is cell temperature, T_{ref} is cell reference temperature (25 ºC).
The cell temperature is as follows

$$T_{ct} = T_{at} + \left(\frac{NOCT - 20}{0.8}\right) G_{in} \quad (2)$$

Where, T_{at} is ambient temperature (20 ºC), nominal operating cell temperature (NOCT) is the temperature reached by a cell in open circuit module under 800W/m^2 insolation.

The efficiency of the PV generator is given as [22]

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{a G_t} \quad (3)$$

$$\text{Fill factor (FF)} = \frac{\text{Maximum PV generator output power}}{V_{oc} \times I_{sc}} \quad (4)$$

Where, I_{sc} is the short circuit current in ampere, V_{oc} is the open circuit voltage in volts, a is the cell area in m^2.
The climate condition i.e. temperature, irradiation, wind speed etc. and pollution (dust) plays important role in the photovoltaic voltage generation. If temperature is increased, there is a marginal increase in PV cell current but crucial reduction in cell voltage. Due to this, cell voltage decreases by approximately 2.2 mv/ºc rise in its operating temperature [23]. The PV module efficiency decreases with increases in temperature. If the solar radiation intensity is increased, both V_{oc} and I_{sc} increase. The power and efficiency increases with increase in intensity of radiation as shown in equation (1) to (4). Pollution i.e. dust, different gases particles etc. also reduce PV generator efficiency.

The voltage, current, and power of a PV generator vary from various solar insolation levels during the day. The system should be reliable, efficient and should provide constant terminal voltage. The maximum power point tracker (MPPT) technique is used for tracking the maximum power point. In this system a buck-boost converter is used with MPPT, to control the input voltage of the voltage sources inverter (VSI).

3.2.2 Converter

DC to DC converters is used for converting the unregulated DC voltage to regulated DC voltage. Buck-boost converter output voltage magnitude may be greater than, equal or less than the input voltage magnitude. The output equation of such a converter is [23-24]

$$\frac{V_o}{V_i} = -\frac{D}{1-D} \quad (5)$$

Where, V_o is the output voltage in volts, V_i is the input voltage in volts, D is the duty cycle.
The efficiency of the converter is as follows

$$\eta_{Con} = \frac{V_o I_o}{V_{pv} I_{PV}} \quad (6)$$

Where, I_o is the converter output current, V_{pv} is the PV generator output voltage and I_{PV} is the PV generator output current.

3.2.3 Inverter

Three phase inverters are used for most of the PV systems. Use of advanced technology and controllable devices e.g. sinusoidal pulse width modulation, space vector modulation etc. reduce the harmonic contents and improve the inverter output. The efficiency of the inverter is as follows [25],

$$\eta_{Inv} = \frac{P_{Inv\_0}}{V_o I_o} \quad (7)$$

Where, P_{Inv_0} is the inverter output power.

3.2.4 Battery and Charge Controller

The Solar generator can generate power only when sunlight is available. There is a need for batteries to store energy and use during the night and time of low sunlight. Overcharging and deep charging reduce the life of a battery. A charge controller controls the charging and discharging of the battery and prevents overcharging and deep charging. The most commonly used batteries in the PV systems are the lead-acid and nickel-cadmium batteries. The battery storage capacity is given in [26]

$$E_{bat} = \frac{(E_{avg} \times DA)}{(\eta_{Inv} \times \eta_{bat} \times DOD)} \quad (8)$$

Where, E_{avg} is the average daily load energy (kWh/day), DA is the daily autonomy of the battery, DOD is battery depth of discharge, η_{Inv} and η_{bat} represent the inverter and battery efficiency respectively.

3.2.5 Diesel Generator

A diesel generator (DG) set is considered as a backup resource. It is used in the non-sunshine hour and emergency conditions when PV source is in outage state. The DG set has to generate AC voltage and connect to the AC bus. DG system should be capable to charge battery and supply the load demand requirement. For optimum DG system operation, accurate energy balance is required. Fuel consumption is directly proportional to the generated power by the DG.

The fuel expenditure of the DG for the generation of electricity is as follows [24]:

$$F_{exp} = F_{ic} P_{dg\_r} + F_{cp} P_{dg\_o} \quad (9)$$

Where, P_{dg_r} is the DG rated power, P_{dg_o} is the DG output power, F_{ic} is the fuel curve intercept coefficient ($0.000205 m^3/h$), F_{cp} is the fuel curve slope ($0.00025\ m^3/h/kW$).

3.3 Economic Optimization Models

The main aim of the economic analysis is to compare PV system with the conventional system. The energy system consists of PV is diurnal and require energy storage for optimal utilization. These complex systems require a systematic evaluation of their economic aspects. Such research work also helps to optimize the provision of finance by concentrating on those applications which are economically justifiable. Many malfunctions can be avoided by proper knowledge of the fiscal and economic strength/limitations of various existing options. LCC is the sum of the cost during its lifetime. In this paper investment cost (IC), replacement cost (RC), salvage cost (SC), operation and maintenance costs (O&M), net present cost (NPC), levelized cost of energy (COE) and total annual cost (AC) were used to evaluate the performance of the hybrid energy system.

Net present cost includes initial IC, RC, O&M and fuel cost (FC) over its entire lifetime (25 yrs). The NPC is as follows [25]

$$C_{npc} = \frac{AC}{C_{CRF}(i,N)} \quad (10)$$

$$C_{CRF}(i,N) = \frac{i(i+1)^N}{(i+1)^N - 1} \quad (11)$$

Where, AC is the total annualized cost ($/year), C_{CRF} is the capital recovery factor, i is the annual interest rate (%), N is the energy system lifetime (year).

The annualized cost (AC) calculates the cost of the system that may occur every year. Therefore, AC is obtained by [21, 26],

$$AC = \frac{LCC}{pw_{re\_beg}} \quad (12)$$

LCC of the system is sum of the present value of all components costs over the lifetime [21, 26].

$$LCC = IC + OM + RC + FC \quad (13)$$

The present worth of recurring investment for the entire life of the system is as follows [27]

$$pw_{re\_beg} = \frac{1}{C_{CRF}(i,N)} \quad (14)$$

The levelized cost of energy (COE) is defined as total annualized cost (C_{AC} in \$/yr) divided by total electrical load supplied (E_s in kWh/yr), using the following equation [27]

$$COE = \frac{C_{AC}}{E_s} \quad (15)$$

The operating cost is the difference between the total annualized cost and total annualized investment cost (C_{AIC} in \$/yr).

$$C_{ope} = C_{AC} - C_{AIC} \quad (16)$$

3.4 Reliability Optimization Models

For optimization of HPVES, it is necessary to find unavailability, system failure rate and MDT of the system. Reliability assessment of HPVES is carried out based on the above indices. F-D technique is used to calculate basic reliability indices.

The concept of frequency and mean duration is based on statistical averages of time to failure and time to repair a system. The concept of frequency is based on the steady-state availability of system and transition rates [28]. The starting point to evaluate frequency and duration is the state transition diagram of the system as shown in Fig. 4.

State probabilities are usually evaluated for two state components system (operable/non-operable) as follows [29].

$$P_k = \frac{\prod_{p \epsilon NOC} \lambda_p \prod_{q \epsilon OC} \mu_q}{DS} \quad (17)$$

Where, λ_p is the failure rate of p^{th} component, μ_q is repair rate of q^{th} component, NOC denote set of non-operable components in k^{th} state, OC denote set of operable components in k^{th} state, q_{ij} is transition rates from i^{th} to j^{th} state.

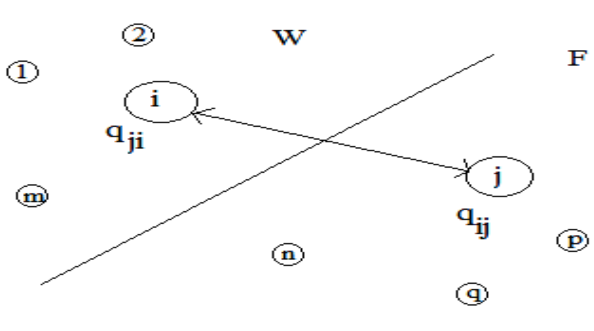

Fig. 4. State transition diagram

$$DS \triangleq \prod_{i=1}^{NC} (\lambda_i + \mu_i) \quad (18)$$

NC =total number of component.

Based on the adequacy criteria the state diagram is divided in two groups of states i.e. W and F. W and F set consists of states corresponding to success and failure of a system. System availability and unavailability are calculated as [29-30]

$$A_{sys} = \sum_{i \varepsilon W} p_i \quad (19)$$

$$U_{sys} = \sum_{j \varepsilon F} P_j \quad (20)$$

Failure frequency is calculated using the following relation

$$f_{sys} = \sum_{i \varepsilon W} P_i \sum_{j \varepsilon F} q_{ij} = \sum_{j \varepsilon F} P_j \sum_{i \varepsilon W} q_{ji} \quad (21)$$

Using eq. (16), (17) and (18) system failure and repair rate is calculated as [28]

$$\lambda_{sys} = \frac{f_{sys}}{A_{sys}} \quad (22)$$

$$\mu_{sys} = \frac{f_{sys}}{U_{sys}} \quad (23)$$

Mean up time (MUT) and mean downtime (MDT) is calculated as [28]

$$MUT = \frac{1}{\lambda_{sys}} \quad (24)$$

$$MDT = \frac{1}{\mu_{sys}} \quad (25)$$

Usually, MDT is expressed in hrs. Similarly U_{sys} is expressed in hrs/yrs. Thus MDT, U_{sys}, λ_{sys} are the basic reliability indices. This relation (21)-(25) are used to evaluate frequency and durations.

4. Case study

In this case study area of the farmhouse is 5 acres. Farmhouse located in (latitude 22.6647° N and longitude 75.8359° E) Indore, Madhya Pradesh, India. The average solar radiation intensity is 5.63 kWh/m^2/day [20]. Farmhouse model is shown in Fig. 3. The Farmhouse includes PV generator, converter, inverter, battery bank and diesel generator (DG) set connected with water pumping system for irrigation and AC lighting load for a house. A PV generator with 3ph/5hp submersible (motor-pump) set is used for irrigation. The borewell depth is 75 m and daily required water is around 35,000 ltr/day. The total size of the PV generator is 5.0 kW including energy reduction due to temperature, dust, and aging. Specification of single PV panel is 0.250 kW and 1.63 m^2 (area). Thus there is a requirement of 20 PV panels with a area

33 m^2. Farmhouse energy consumed by HPVS was calculated is about 7 kWh/day with 2 kW peak load.

Case 1: LCC Analysis

PV based different systems are compared and obtained a most efficient, cost-effectiveness and reliable system by using LCC analysis. PV arrays lifetime is taken as 25 years. The total investment cost (IC) of 5kW PV generator is $3,530. The inverter IC is $809.00 and replaced every 7 years and $170 for a converter which is replaced every 7 years. The total net present cost (NPC) and annualized costs are $5,881 and $407.35 respectively. Solar PV water pumping system cost of energy ($/kWh) is $0.0900. Battery IC is $1470 which is replaced every three years, $368 for a converter which is replaced every 7 years. The whole system for LCC analysis inflation rate and the discount rate has taken 8% and 10% respectively. Schematic architecture model of the farmhouse system is shown in Fig. 5.

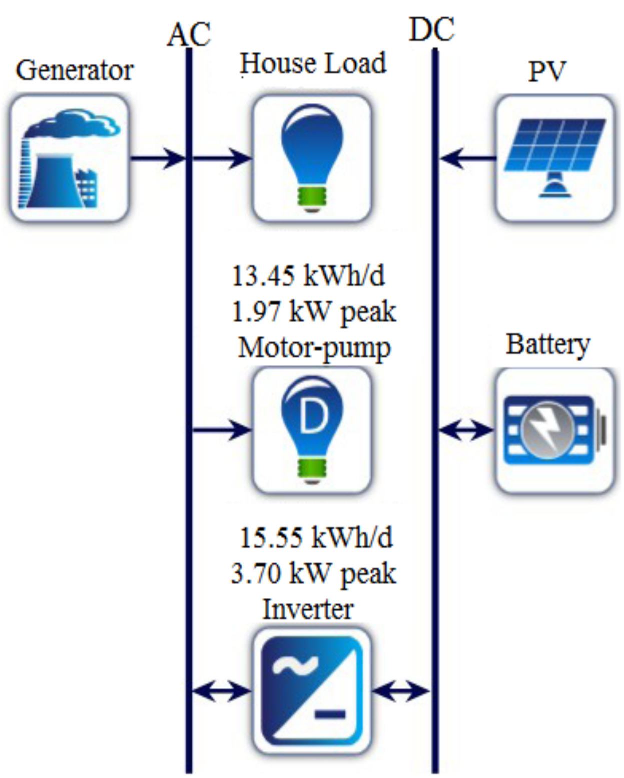

Fig. 5. Schematic architecture model of the farmhouse system

LCC of solar PV and diesel system configurations are calculated by using HOMER Pro software. The following configurations are possible:

- PV system without battery backup
- PV system with battery backup
- PV system/battery/diesel generator
- PV/diesel generator without backup
- Diesel generator without battery backup
- Diesel generator with battery backup

The complete LCC (IC, OC, NPC AC, and COE) of the configurations are calculated and shown in Table 1. The lifetime of DG is considered to be 8 years. Thus it needed to be replaced in every 8th, 16th and 24th year. The diesel generator 1 kW cost is $200. The O&M and cost of the diesel are taken $50/year and $1/ltr respectively.

Table 1. LCC analysis of solar PV and diesel system configurations

System configura tions	IC ($)	OC ($)	FC ($)	NPC ($)	COE ($/k Wh)	AC ($)
PV only	$4,3 07	$1,3 35	0	$5,64 2	$0.0 661	$390 .84
PV with battery backup	$5,8 34	$1,6 10	0	$8,03 5	$0.0 783	$556 .57
Diesel only	$620 .00	$3,9 20	$67,9 15	$73,0 63.97	$0.4 79	$5,0 61
Diesel with battery backup	$2,6 97	$3,8 02	$60,3 61	$67,9 09.24	$0.4 45	$4,7 04
PV/diesel without backup	$4,9 84	$4,9 70	$48,6 02	$59,1 03	$0.3 87	$4,0 94
PV/batter y/diesel	$6,3 40	$3,6 41	$32,1 81	$43,2 60	$0.2 84	$2,9 97

Economic comparison of solar PV system and diesel generator based system configuration is shown in Figure 6.

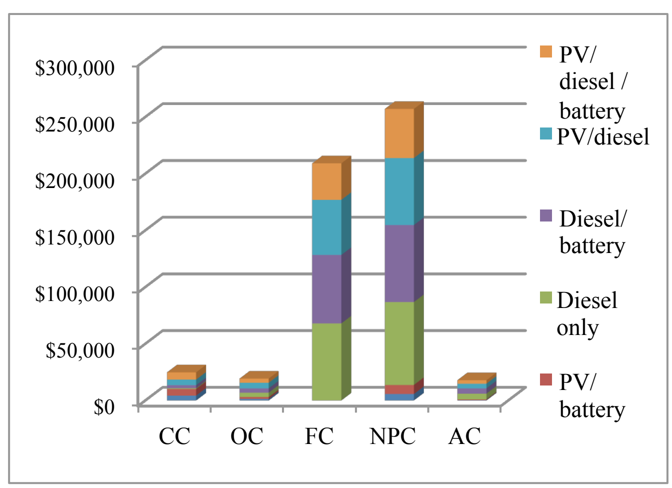

Fig. 6. LCC comparisons of solar PV and diesel system configurations

It is clear from Fig. 6, the IC cost of the PV system is higher than DG based systems. DG system OC, FC, and NPC are higher than PV systems.

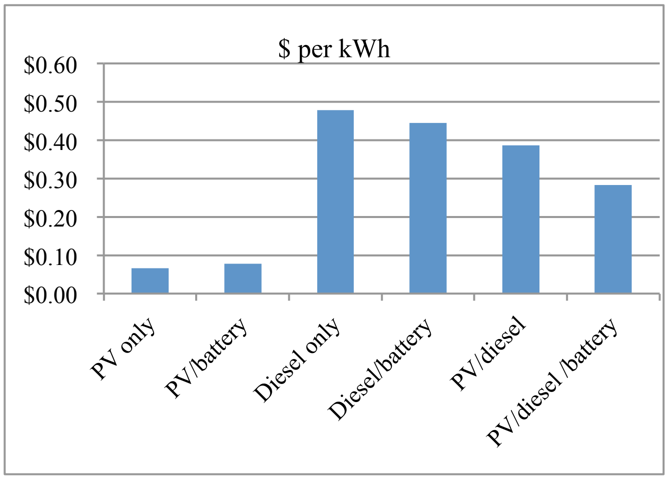

Fig. 7. COE ($/unit) of each configuration

Figure 7 shows per unit cost of electricity (COE) from solar PV only is $0.0661, PV/battery is $0.0783, PV/battery/diesel is $0.284, PV/DG is $0.387, DG/battery is $0.445 and DG is $0.479. Clearly, the COE is least for solar PV system as compared to DG system. PV system alone may not meet reliability requirements.

PV only and PV/battery system electricity shortage is 40% and 20% annually respectively. This system is not a feasible system.

Global warming is the continued rise due to increasing emissions of CO_2, CO, SO_2, NO_x and other pollutant gases. These pollutant gases are produced by burning fossil fuels. These pollutant gases are also degrading the environment and harmful effect of human being. Renewable energy sources are environmentally friendly, non-polluting and remedy of global warming. Table-2 shows comparison of GHG emissions (kg/year) of different energy generated configurations.

Table 2. Comparision of GHG emissions (kg/year) of different configurations

Pollutant	PV/battery/diesel	PV/diesel	Diesel/battery	Diesel only
Carbon Dioxide (CO_2)	5835	8812	10945	12314
Carbon Monoxide (CO)	36.8	55.5	69	77.6
Unburned Hydrocarbons	1.61	2.42	3	3.39
Particulate Matter	0.223	0.337	0.418	0.479
Sulfur Dioxide (SO_2)	14.3	21.6	26.8	30.2
Nitrogen Oxides (NO_2)	34.6	52.2	64.8	72.9

It is observed that from economic and environmental point of view PV/battery/DG system is more adequate system for irrigation as well as farmhouse load.

Case 2: Reliability Evaluation using F-D Technique

Reliability network of HPVES is shown in Fig. 8, which consists of PV system with battery backup and DG set as standby.

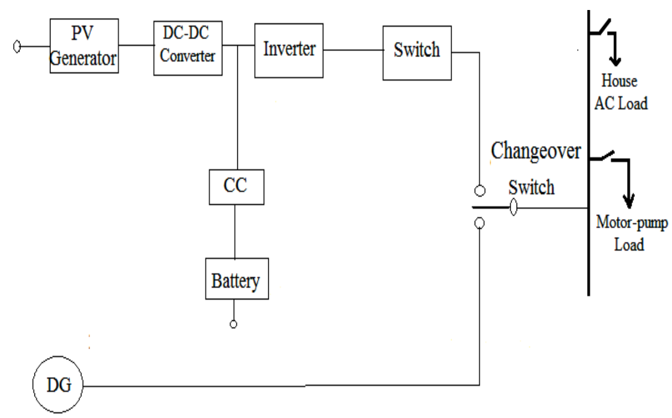

Fig. 8. Reliability network of HPVS

Failure and repair rates have been computed on the basis of previous five years study period and given in Table 3.

Table 3. Failure and repair rate of HPVES components [17,30]

S. No.	Components	F. /yr.	R. /yr.
1	PV array	0.05	292
2	Buck-Boost converter	0.037	175
3	Inverter	0.095	175
4	Switch	0.08	365
5	Charge controller	0.03	175
6	Battery	0.01	876
7	DG	0.5	122
8	Changeover switch	0.01	1752

Reliability indices are calculated for different configurations using equation (16) to (21). Calculated indices are given in Table 4.

Table 4. Reliability indices of different configurations

S. No.	Reliability indices	PV only	Diesel only	PV/battery	Diesel /battery	PV/diesel	PV/battery/diesel
1	U_{sys}	9.636	35.916	6.671966	0.083761	0.893	0.07723254
2	f_{Sys}	0.2617	0.5079	0.1749	0.0113	0.0116	0.0111
3	λ_{sys}	0.2620	0.5100	0.1750	0.0113	0.0116	0.0111
4	MDT	38.2880	70.4938	38.1480	7.3819	7.6904	6.962327134

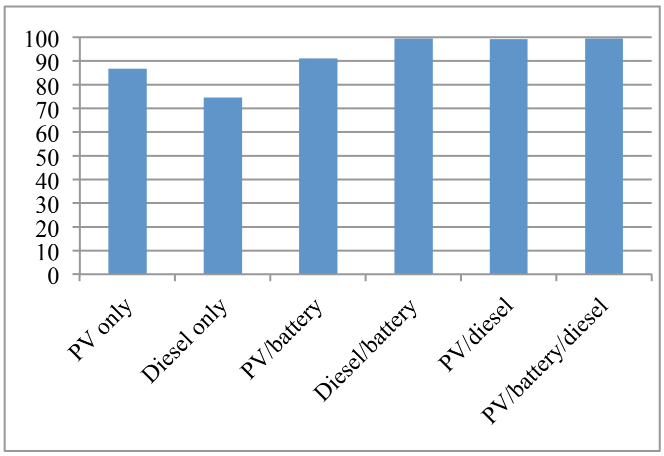

Fig. 9. Hybrid PV system configurations availability in %

Figure 9 show that PV/battery/diesel system has availability more than other configurations. Figure 10 show HPVES components availability. DG system and inverter have least availability among all the components.

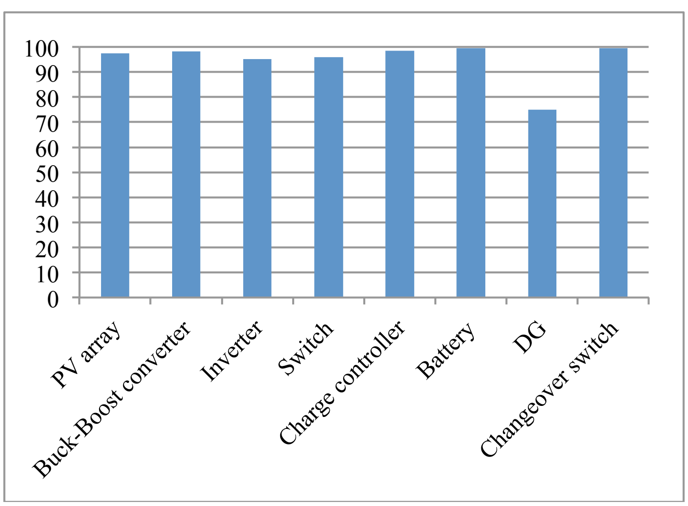

Fig. 10. Hybrid PV system components availability in %

PV/battery/diesel system unavailability (0.07723254), failure rate (0.0111) and MDT (6.962327134) are less compared to other configurations. It is clear from the above results PV/battery/diesel system is more reliable among the configurations.

5. Conclusion

In this paper, economic and reliability evaluation of hybrid PV/diesel/battery energy system for farmhouse load has conducted. To obtain the most economical and reliable solution of location area, six different system configurations e.g. PV only, diesel only, PV/diesel, PV/battery, PV/diesel/battery, diesel/battery, were considered. The economical and reliability assessment has been carried out by HOMER software and F-D technique respectively. According to the results for the selected region in this study, it is concluded that:

- PV/battery/diesel system configuration is found as optimum system for irrigation as well as farmhouse electricity load on the basis of NPC ($43,260), COE ($0.284/kWh) and AC ($2,997).
- PV/battery/diesel system configuration also exhibits fewer emissions of gases as compared to other configurations as shown in Table 2.
- Diesel only system emits 12314 kg and 77.6kg of CO_2 and CO per year respectively and higher COE ($0.479/kWh).
- Diesel/battery is also not a good option for selected study area.
- PV/battery/diesel system unavailability (0.07723254), failure rate (0.0111) and MDT (6.962327134) are less compared to other configurations. These indices can provide an improved physical appreciation of the reliability performance of a system.
- DG system and inverter have least availability among all the components.
- It is clear from the above results; PV/battery/diesel system is more cost-effective, reliable and environmental friendly system among the other configurations.

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