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Research Article

Designing of a Feasible Low Pollutant Grid Integrated System for Steel Plant

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Abstract

This paper presents system architecture with low pollutant emission for application in Bhilai Steel Plant (BSP) located in Bhilai, Chhattisgarh, India. Chhattisgarh is very rich in terms of renewable resources like solar, wind and biomass. The availability of solar radiation in this region is significantly rich for any kind of solar generation options. The government provides widespread support for the use of renewable energy, particularly solar and wind which provides power without additional pollutants. These natural energy sources can be harnessed for electricity generation which depends upon the cost and efficiency of technology that is constantly improving to reduce the costs per kWh on the source. Solar energy utilization becomes complex due to supply and demand logic. Also, a backup generating capacity is required due to its intermittent nature, escalating the cost of the system with an increasing proportion of variable renewable sources. Many countries including India, have policies to support renewable to confer priority in the grid system by subsidizing them. The analysis is carried out by investigating the potential of solar energy and collecting data from BSP. In this paper, the existing system is modelled with one option of solar grid integrated system so as to have a low pollutant emission system, together with cost-saving. The existing system is taking power from power plant (PP) and grid NTPC-SAIL Power Corporation Limited (NSPCL) whereas a solar grid integrated system is also modelled as an option for future energy sources.

Keywords: Pollutant Emission, Net Present Cost,Levelized Cost of Energy, Photovoltaic system, Grid.

1. Introduction

BSP is the sole producer of rails for Indian railways and the task of designing and analyzing a system for such a plant appears daunting due to uncertainty in key parameters such as demand profile, fuel price hikes and availability of number of designs Ryu.J.H et.al [1] & Makhija.S.P et. al.[2]. Together with use of renewable adds further complexity due to its nature of availability, seasonal variations, non-dispatch, intermittent output power etc Simon. R et. al[3]. Here a system is required to be designed to overcome the challenges of a flexible power system design focused on pollutant emissions, cost optimization etc by using an integrated system simulated in Hybrid Optimization Model for Electrical Renewable (HOMER). This software is well employed for simulating the entire power system of the steel plant under research. HOMER is a computer model meant for optimization of micro power systems developed by the U.S National Renewable Energy Laboratory (NREL) to facilitate the micro power system design and to compare the technologies of power generation with a wide range of applications as mentioned by

Navamani et al. [4]. It can model grid connected systems and also off grid system with combination of solar photovoltaic (PV) modules serving various thermal and electrical loads. It models life cycle cost, physical behaviour etc. of a power system. In this paper two systems have been designed; one is the existing functioning system of plant and as an option to current system whereas another system is designed using an integrated solar grid system. HOMER compares the different design options based on the basis of economics, technical and physical behaviour and selects the best possible designed system. HOMER named it as "The Winning System Architecture" which is nothing but the PV grid integrated model as explained in this paper. The designed solar grid integrated system provides the best suitable option to fulfil the current power system requirements of plant as compared to its existing that is grid system only.

2. Methodology

This section describes designing of system architecture for the existing and proposed system and provides load profile of BSP, propagation of solar radiation from sun to earth's surface with solar radiation data for specified latitude.

2.1. Demand side profile

A solar supply strongly depends upon climate and latitude, their availability directly affects the economics of designing power system since it determines the emissions and quantity of production Nurunnabi. M. et. al.[5]. Table 1 summarizes the geographical location of BSP. The term load means modeling of electrical or thermal load.Fig.1 represents the hourly and seasonal load profile of BSP.

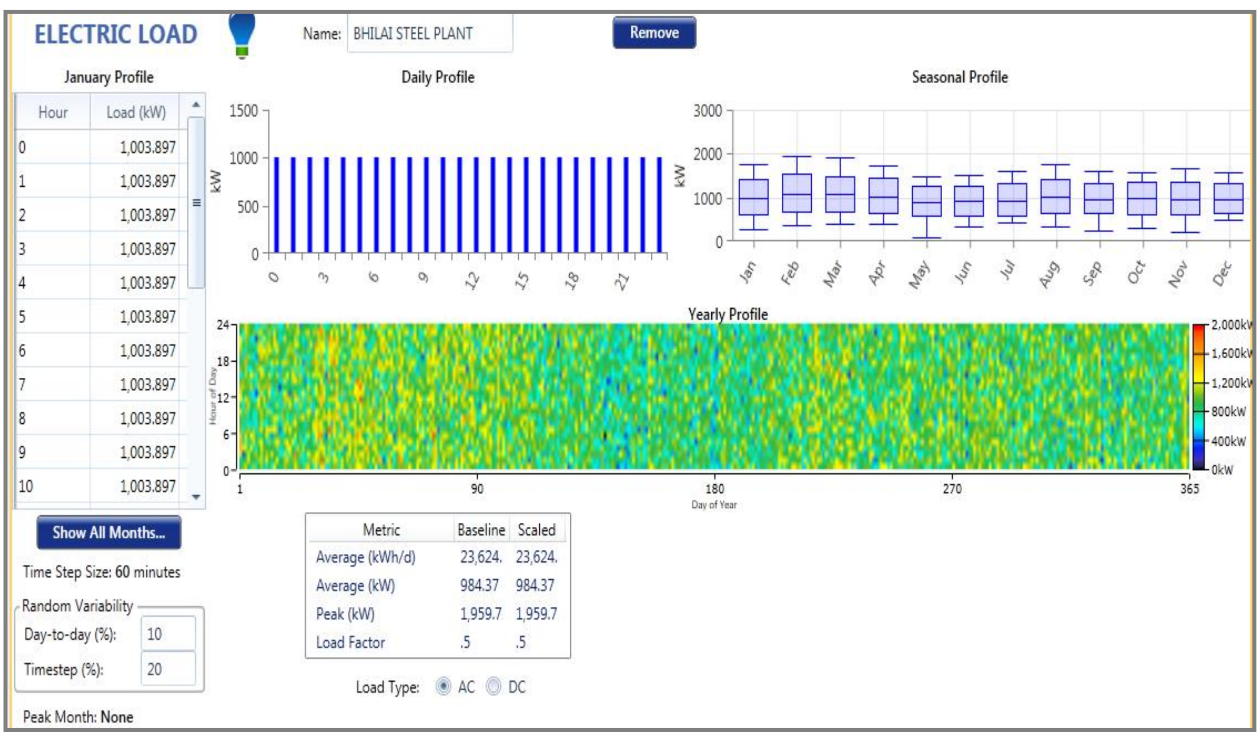

Fig.1 Power load profile of BSP

2.2 Solar radiation and its computation

Solar resource data indicate the yearly amount of global solar radiation, which comprises of diffuse radiation coming from all parts of the sky and direct beam radiations striking Earth's surface. The same phenomenon is represented by equations (1) to (9). Solar radiation flux sometimes is also represented in Langley's per hour or per day, where 1 Langley = 1cal/cm ^{2} = $1.163*10^{-2}$kWh/m^2.

Table 1: Site specifications of BSP

Parameter	***Unit***	***Climate data location***
Latitude	°N	21.5
Longitude	°E	81.5
Elevation	m	391
Heating design temperature	°C	13.70
Cooling design temperature	°C	36.78
Earth temperature amplitude	°C	18.07
Frost days at site	day	0

The solar time can be calculated using

$$t_s = t_c + \frac{\lambda}{15°/hr} - Z_c + E \quad (1)$$

t_c = Civil time in hours corresponding to midpoint of time step hour.
λ = Longitude [°].
Z_c = Time zone [hours].
E = Equation of time.
Whereas, the equation of time for obliquity is calculated by:-

$$ET = 3.82[(.000075+ .001868.\cos B-.032077.\sin B-.014615.\cos 2B-.04089.\sin 2B@)] \quad (2)$$

Where,

$$B= 360\frac{(n-1)}{365} \quad (3)$$

n= day of year.
The angle between the sun's beam radiation and normal to surface that is the angle of incidence and it is calculated by:-

$$\cos\theta = \sin\delta\sin\text{Ø} \cos\beta - \sin\delta\cos\text{Ø} \sin s\beta \cos\gamma + \cos\delta \cos\beta \cos\text{Ø}\cos\omega + \cos\delta\sin\text{Ø} \sin\beta \cos\gamma\cos\omega + \cos\delta \sin\beta \sin\gamma\sin\omega \quad (4)$$

θ= Angle of incidence [°]
β= Slope of surface [°]
γ= Azimuth of surface [°] (5)
Ø= Latitude [°]
δ = Solar declination [°]
ω = Hour angle [°]
By using above equation the zenith angle is can be calculated as:-

$$\theta_z=\cos\text{Ø}\cos\delta\cos\omega+ \sin\text{Ø}\sin\delta \quad (6)$$

$\theta_{z=}$ Zenith angle [°]

The amount of solar radiation striking a surface normal to sun's ray at top of earth's atmosphere is defined as extraterrestrial normal radiation and is given by:- (7)

$$G_{on} = G_{sc}\left(1 + .033 \cos\frac{360n}{365}\right) \quad (8)$$

G_{on} = Extraterrestrial solar radiation [kW/m^2]
G_{sc}= Solar constant [1.367 kW/m^2]
n = Day of year. (9)
The amount of solar radiation striking a horizontal surface at top of earth's atmosphere is defined as extraterrestrial horizontal radiation and is given by $G_o = G_{on} \cos \theta_z$
The average extraterrestrial horizontal radiation over a time step is given by:-

$$\bar{G}_o= \frac{12}{\pi}G_{on}\left[\cos\text{Ø}\cos\delta(\sin\omega_2 - \sin\omega_1) + \pi\frac{(\omega_2-\omega_1)}{180°}\sin\text{Ø}\sin\delta\right]$$

$\bar{G}_o$ = Extraterrestrial horizontal radiation average over time step [kW/m^2]
ω_1 = Hour angle at beginning of time step [°]
ω_2 = Hour angle at beginning of time step [°]
The clearness index is the ratio of striking solar radiation in earth's surface

to the solar radiation striking at top of atmosphere or in other words it represents a visible index or clarity index of atmosphere and is given by;-

$$k_T = \frac{\bar{G}}{\bar{G}_o}$$

$\bar{G}$ = Global horizontal radiation on earth's surface averaged over time step [kW/m^2]

$\bar{G}_o$ = Extraterrestrial horizontal radiation averaged over time step [kW/m^2]

The global solar radiation is:-

$$\bar{G} = \bar{G}_b + \bar{G}_d$$

$\bar{G}_b$ = Beam radiation [Kw/m^2].

$\bar{G}_d$ = Diffuse radiation [Kw/m^2]

Fig.2 and 3 shows the month wise solar radiation with 6.710 kWh /m^2/day as maximum solar radiation in month of April followed by May, whereas the minimum radiation is 3790 kWh /m^2/day in month of August. Here the clearness index is 0.639, the average radiation is 5.08 kWh /m^2/day and the highest temperature is 32.850°C as spotted by HOMER resources. The average wind speed in this region is 2.7m/sec.

2.3. System Architecture

System architecture defines system configuration, components combination for system, size and the strategy which all together defines the working of whole system as one over its entire life period. After that the simulation process serves two purposes; one is feasibility of defined system which satisfies to serve the required load with other imposed constraints and other is to estimate the life cycle cost of whole system which includes cost of installation and operation over its life time. The modelling of a particular system configuration is achieved through an hourly time series simulation of its operation yearly.

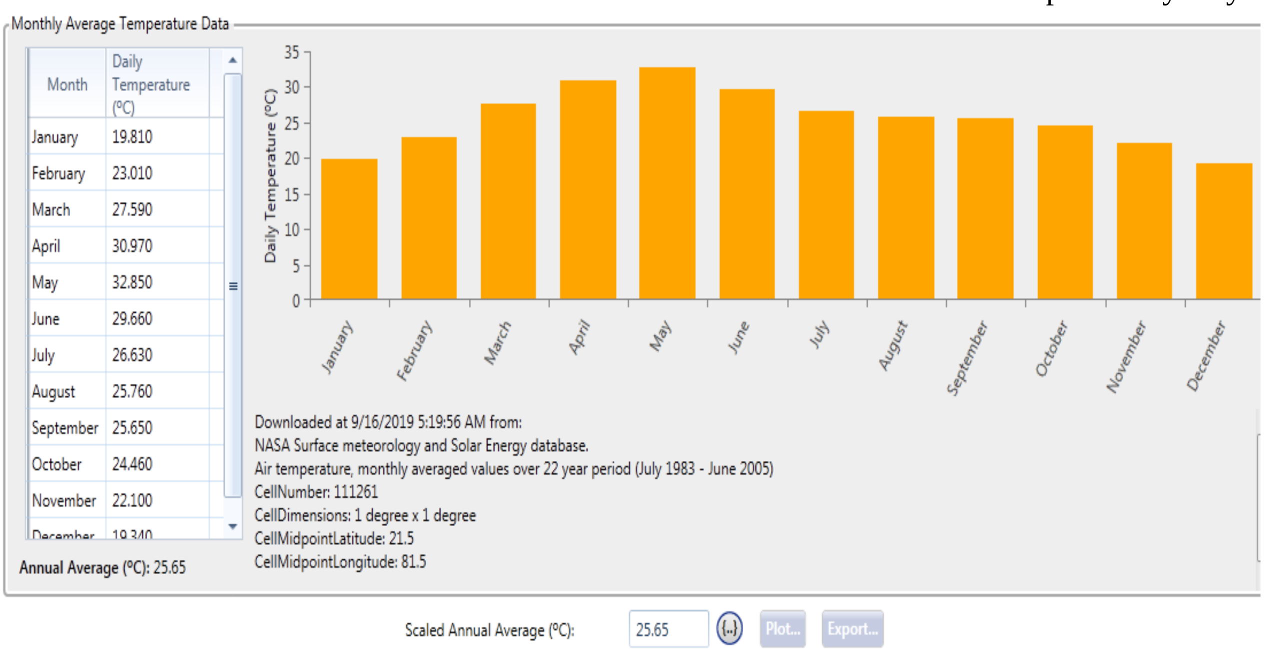

Fig.2 Monthly solar GHI resources

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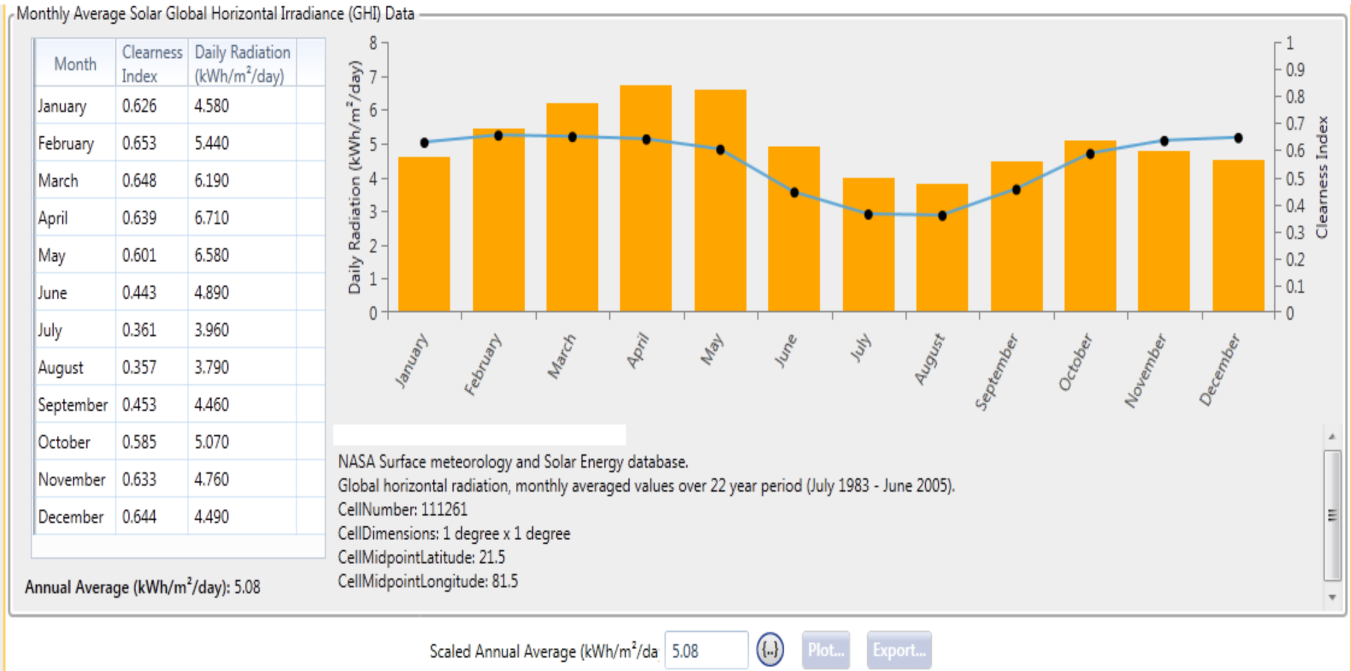

Fig.3. Monthly temperature variation.

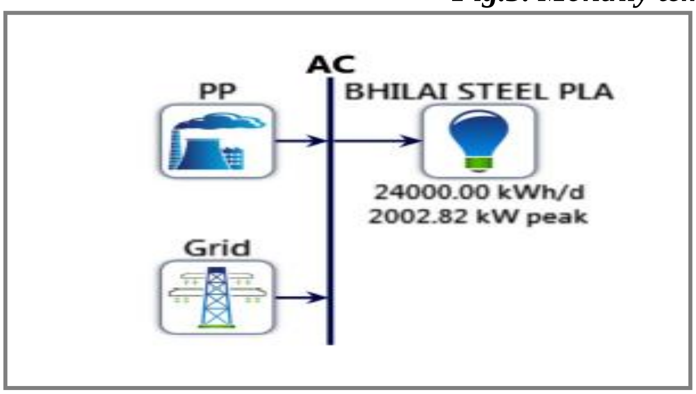

Fig.4. ***The arrangement of existing system.***

2.3.1 existing system of BSP

For this system, plant simulations are done which is operating with grid supply and with its own captive generation plants (PP). Here the same existing system is modelled by considering the plant load in HOMER as shown in fig.4.

2.3.2 Proposed solar grid integrated system for BSP

For this system, plant is operating with grid supply, captive generating plants PP and solar PV system as shown in Fig.5.

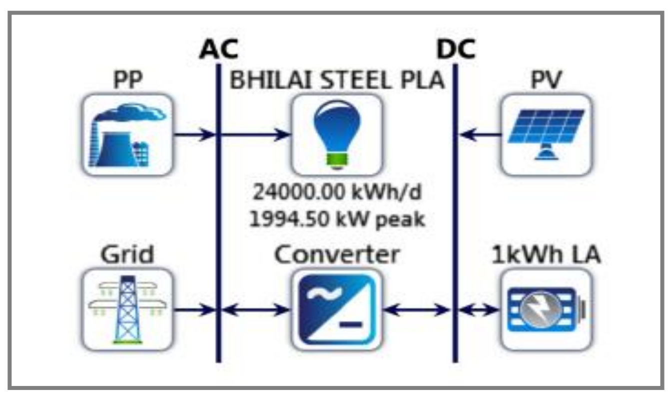

Fig.5. ***The arrangement of solar grid integrated system.***

The whole system is simulated in HOMER simulator and is considered as winning system architecture by HOMER simulator.

3. Results and discussion

This section deals with illustration of simulation output, tables and graphs. To novice viewers understanding the proposed method is compared with the existing system of BSP using HOMER. In this process of optimization HOMER discards the infeasible systems and simulates the feasible one ranking with lowest NPC, LCOE, pollutants etc. The term infeasible means the constraints which are not satisfied. It computes the required quantities to calculate the life cost of system such as power purchased from grid annually, generator operating hours annually, expected battery life, annual fuel consumption. Finding an optimal system configuration involves deciding the mix of components that the system should contain, the size or quantity of each component, and the dispatch strategy the system should use.

3.1 Economic modelling

Economics emphasizes on lowest NPC, LCOE system. It plays an integral role to go with any designed power system. The cost characteristics of renewable and nonrenewable sources varies drastically as the renewable sources tend to have high initial capital cost and low operating cost whereas the nonrenewable sources have low capital cost and high operating cost on account of maintenance needed for various electrical components employed in power generation means.

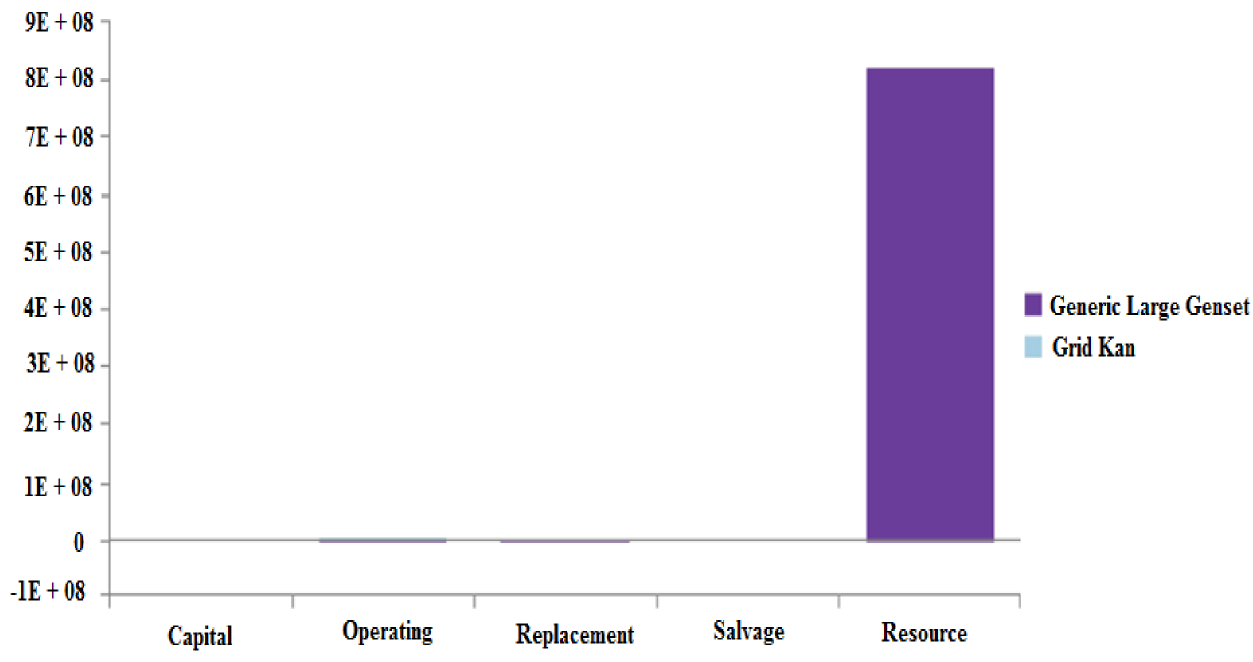

Fig.6 ***NPC of existing system.***

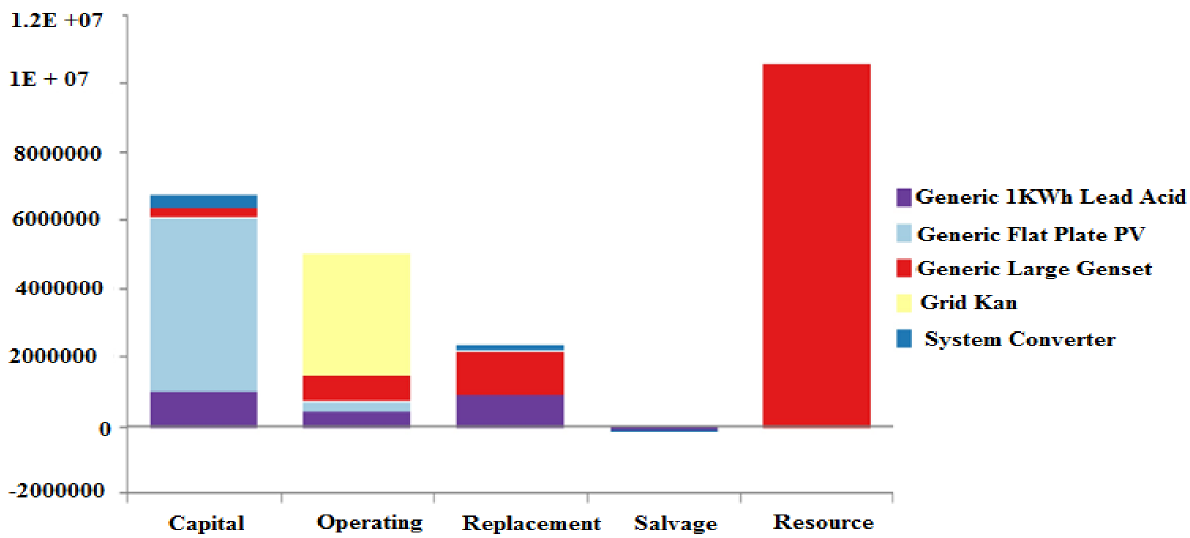

Fig.7. ***NPC of solar grid integrated system***

3.2 NPC

NPC represents the total life cycle cost of system which includes the cost of initial construction, maintenance cost, fuel cost, component replacement cost in addition with cost of power purchased from grid within the project life time with the discounted present cash flows for future as shown in fig.6 and 7 for the two systems. It also includes the penalties imposed due to pollutant emissions and with the revenue returns from the sale of power to grid the NPC gets reduced. Revenue return is a negative parameter and it includes salvage cost, power sold to grid at end of project life.

NPC of existing system is 83,35,92,700 Rs. comprises of 6.69MRs. Capital cost, 4.39M Rs. operating cost, 2.31M Rs. replacement cost, -163,558 salvage and 10.6M Rs. resource cost whereas NPC of solar grid integrated system is 2,44,44,170 Rs. comprises of 600,000MRs. Capital cost, 8.21M Rs. operating cost, 3.01M Rs. replacement cost, -112,592 salvage and 822M Rs. resource cost.

3.3 Production Summary

The production summary for the two systems has been shown in table2 whereas fig.8 shows the graphical representation of production summary of the two designed systems.

Table 2 Production Summary

System	***Component***	***Production(kWh/yr)***	***%***
Existing System	Generic Large Genset	37,18,811	41.5
	Grid Purchases	52,42,179	58.5
	Total	89,60,989	100
Integrated System	Generic Flat Plate PV	35,42,412	37.8
	Generic Large Genset	30,63,472	32.6
	Grid Purchases	27,77,389	29.6
	Total	93,83,272	100

Table 3 Renewable Summary

Capacity Based Metrics	***Value***	***Unit***
Nominal renewable capacity divided by nominal capacity	66.7	%
Usable renewable capacity divided by total capacity	61.5	%
Energy Based Metrics	***Value***	***Unit***
Total renewable production divided by load	40.5	%
Total renewable production divided by generation	37.8	%
One minus total renewable production divided by load	65.0	%
Peak Values	***Value***	***Unit***
Renewable output divided by load	521	%
Renewable output divided by total generation	100	%
One minus nonrenewable output divided by total load	100	%

Table 3 shows the overall renewable production summary of solar grid integrated system in which capacity-based metrics decides the nominal and usable capacity in percentage, energy based metrices represents the fraction of renewable production in terms of total load and total generation with their peak values.

3.4 Pollutant Emissions

The types of pollutant emissions calculated includes carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (UHC), particulate matter (PM), sulphur dioxide (SO_2), nitrogen oxides (NO_X), of which only CO_2 is a non-toxic gas. These pollutants emit from generators during electricity generation and by electricity consumption from grid. Pollutants for the two systems are represented graphically here in fig.9 and fig.10 for overall pollutants and CO_2.

In solar grid integrated system: -

$$N = G_P - G_S \quad (10)$$

where,

N = Net grid purchase.

G_P = Total grid purchase.

G_S = Total grid sales.

The net grid purchase (kWh) is multiplied by emission factor (g/kWh) for each pollutant. The grid related pollutant emissions become negative when the system sells more power to grid then it purchases from grid annually, also the net grid purchase becomes negative as expressed by equation (10).

The emission level of CO_2 is reduced from 60, 15,494 to 29, 10,252 kg/year in solar grid integrated system which is just half and makes the overall winning system as less pollutant. Similarly, the emission level of CO is reduced from 14,375 to 9159 kg/year, PM from 123 to 75.3 kg/year, SO_2 from20, 826 to 10,878 kg/year UHC from 763 to 392 kg/year and NO_X from 9618 to 3858 kg/year respectively in solar grid integrated system which makes the overall winning system less pollutant.

The NPC for solar grid integrated system is Rs.2, 44, 44,170 which is less as compared to the existing system of plant, also the levelized cost of energy is only 0.216 Rs/Kwh which is very economical.

Discounted payback is 6.90years and the simple payback is 10.5 years with solar grid integrated system whereas it is nil in case of existing system due to absence of alternative energy options.

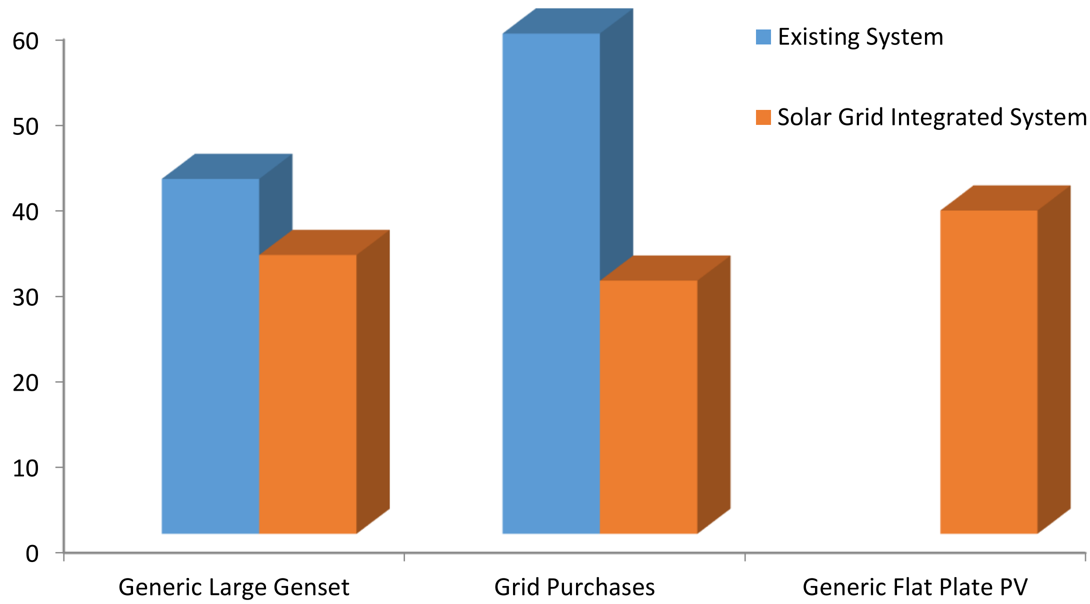

Fig.8. ***Production Summary***

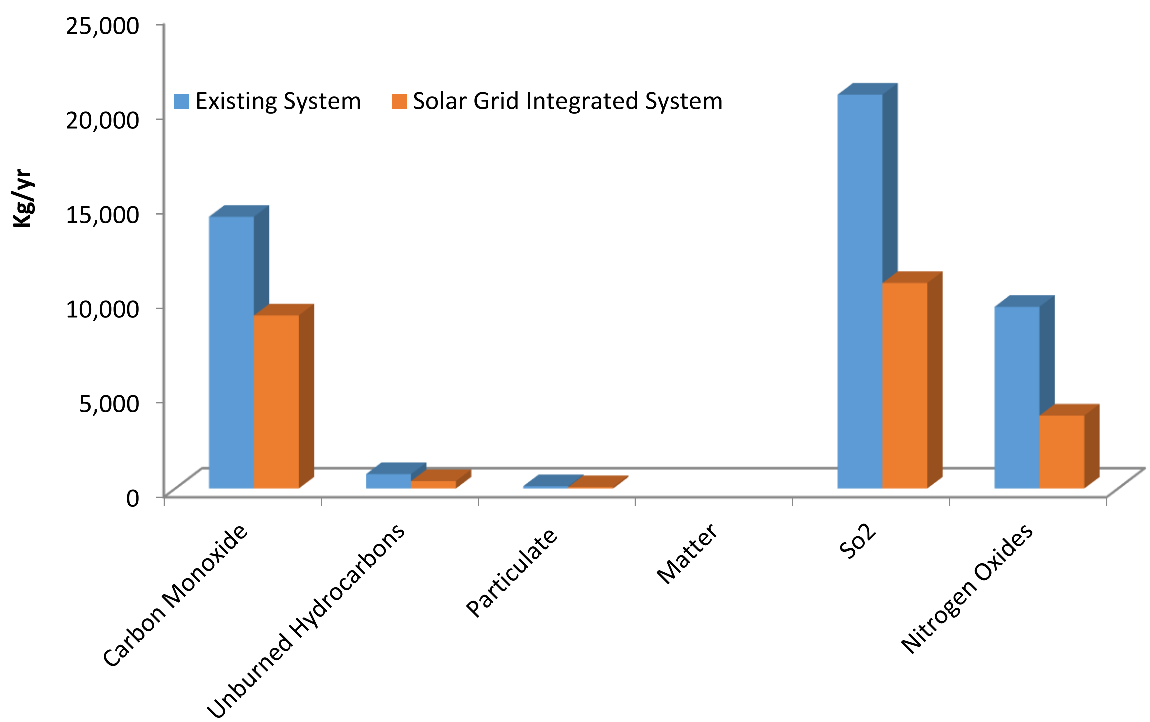

Fig.9. ***Pollutant emissions***

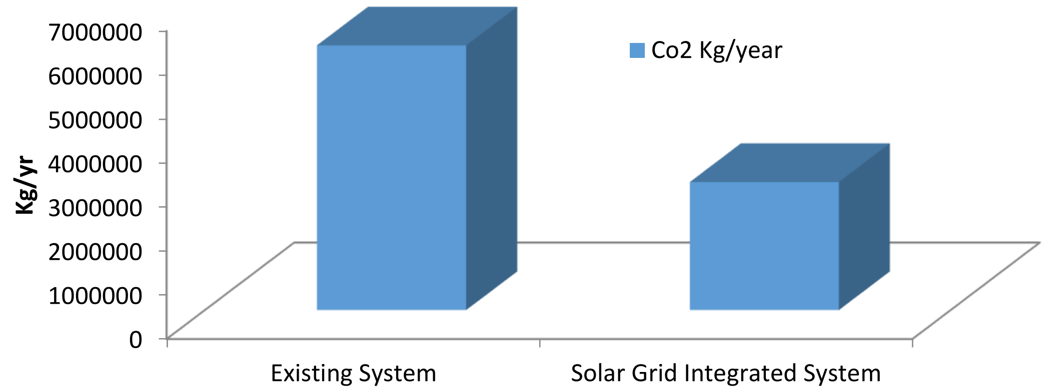

Fig.10. ***CO_2 emissions.***

Hence the solar grid integrated system provides the overall generation with 32.6% from internal sources 37.8% from PV system and 29.6% purchased from Grid as shown in Fig.3.4.

Conclusions & future scope

In the study carried out the system optimized closely according to the system of plant is the solar grid integrated system and is dominant as most feasible system over the existing plant system with less percentage of pollutants. HOMER has found different optimal system for BSP and with the lowest NPC and pollutants with the discounted payback 10.5 years and the simple payback 6.5 years for the winning system architecture whereas it is nil in case of existing system of plant. Further sensitivity analysis cases can be made a part of this entire research.

Conflict of interest

The author declares no conflict of interest.

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