Design and feasibility analysis of hybrid energy-based electric vehicle charging station

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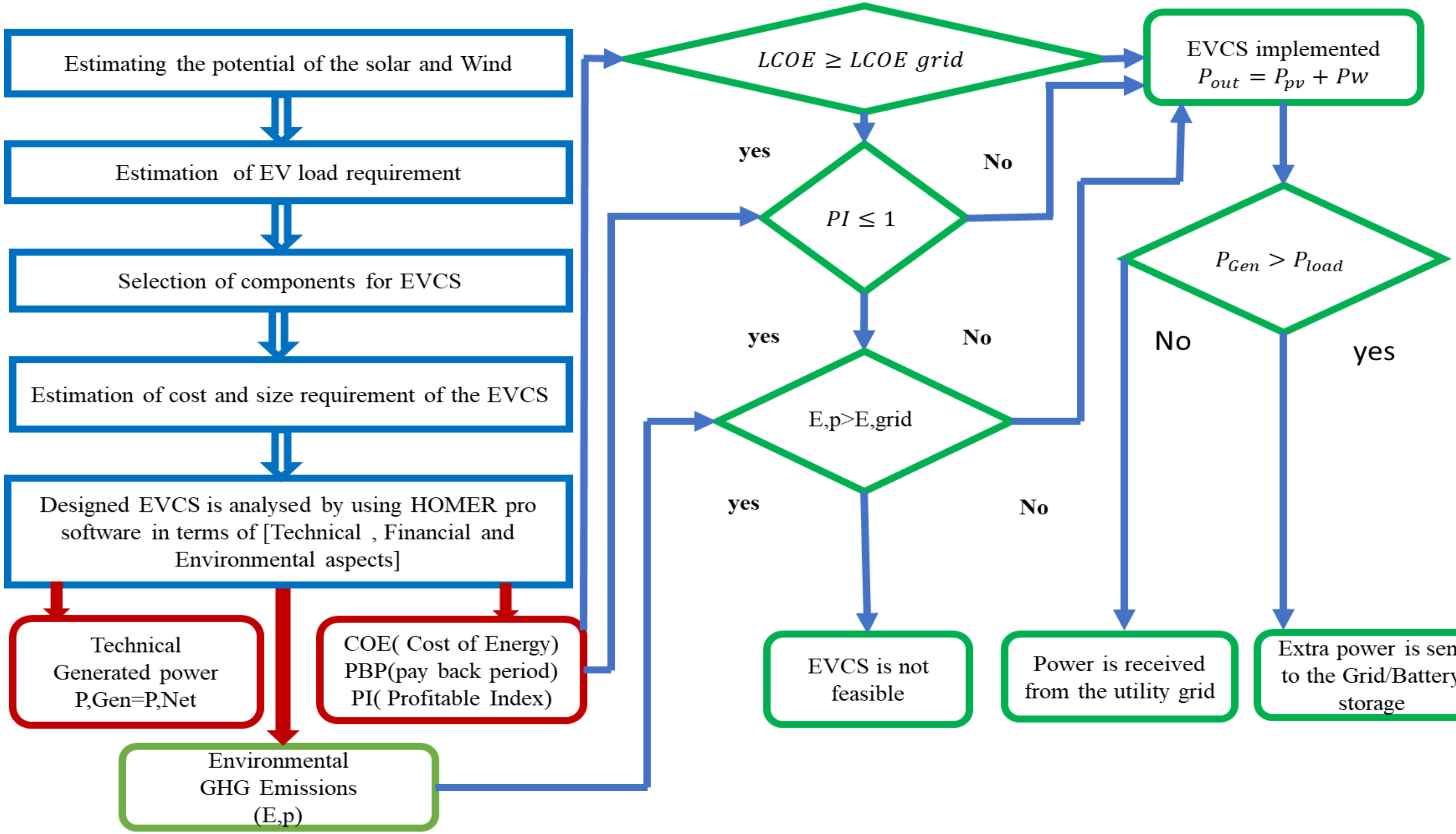
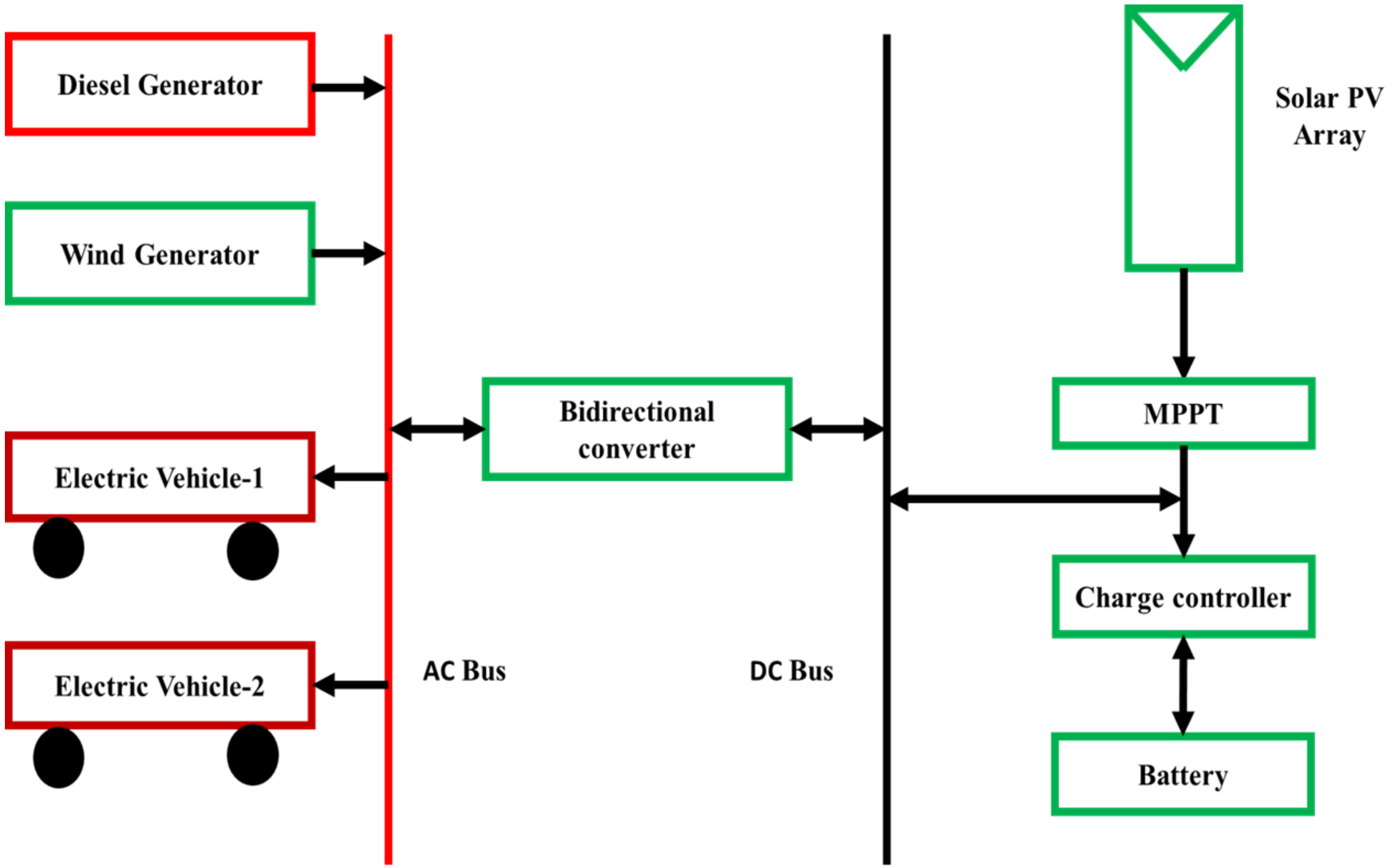
Objective of the presentation

- To develop a novel model for an **EVCS using hybrid energy sources**.
- To perform **optimum sizing and techno-economic analysis of the proposed system**.
- To analyze the proposed system in both **grid-connected** mode of operation and **autonomous mode of operation**.
- **Sensitivity analysis** of the system. (The effect of fuel cost variation, inflation rates and discount rates are considered to understand the variation of LCOE and NPC.)

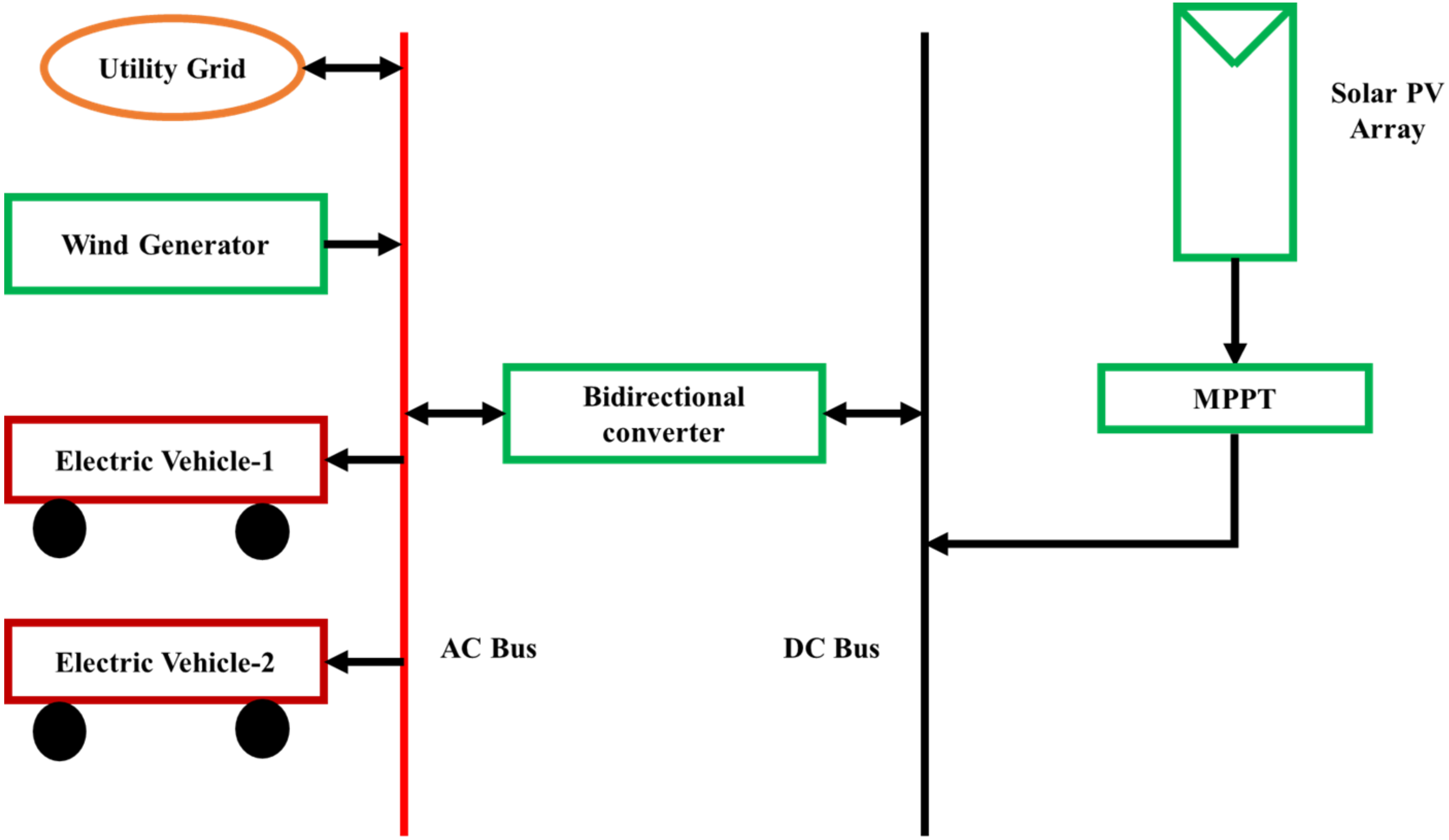
Methodology adopted



Autonomous mode EVCS



Grid-connected mode EVCS



Mathematical modelling of the proposed system

The output power of the PV module is calculated by using equation:

$$P_{Sol(t)=P_{rat}} f_{loss} \frac{G_h}{G_s}[1+\alpha_p (T_C\text{-}T_s)] \quad (1)$$

P_{rat} indicates solar power output capacity, f_{loss} indicates loss factor, G_h indicates hourly solar incident radiation on solar panel, $G_s$indicates standard incident radiation (1000W/m^2) α_p indicates temperature coefficient of the power.

Electrical power output from the wind turbine system is calculated as:

$$P_e = \frac{1}{2} \times \rho \times C_p \times A \times V^3 \times 10^{-3} \quad (2)$$

Cp represents the power coefficient of the wind system , ρ represents the air density.
A represents the surface swept by the rotor in (m^2) and V indicated wind speed (m/s).

Mathematical modelling of the proposed system

The power supplied to the grid is calculated by using equation:

$$P_{gs}(t)=[P_{pv}(t)\eta_{inv}+P_w(V_v)(t)]-P_L(t) \quad (3)$$

The amount of power drawn from the grid is calculated by using equation:

$$P_{gp}(t)=P_L(t)-[P_{pv}(t)\eta_{inv}+P_w(V_v)(t)] \quad (4)$$

Power consumed by the electric vehicle depends upon three factors, namely, distance travelled, battery capacity, and mode of driving. Power consumed by the electric vehicle can be calculated by using equation:

$$P_C = \frac{K_d.E_k}{T} \quad (5)$$

K_d indicates, number of kilometres driven, E_k indicates the energy necessary to drive the vehicle. T is the time required to charge the vehicle.

Mathematical modelling of the proposed system

The power demand of the N^{th} electric vehicle can be calculated using equation:

$$P = \sum_{i=1}^{N} P_C \quad (6)$$

The energy required by the battery can be calculated by using equation:

$$Q_{Battery} = SOC + \int_0^t V_{bat} I_{bat} dt \quad (7)$$

SOC indicates the initial value of the charge of the battery.

The rating inverter can be calculated by using equation:

$$P_{inv}(t) = P_{pv}(t)\eta_{inv} \quad (8)$$

$$P_{pv}(t) = P_{sol}(t)N_{sol} \quad (9)$$

Mathematical modelling of the proposed system

In an integrated grid system, the size of the inverter depends on grid sale capacity and local load demand.

$$P_{max.inv}=P_{L.max}(t)+P_{gs.max} \quad (10)$$

LCOE is defined as the ratio of the sum of the entire cost collected during the Project lifespan to the number of kWh generated over the entire lifetime of the project.

$$LCOE= \left(\sum_{i=0}^{T}\left[\frac{C_i+L_i+O\,\&\,M_i+I_i}{(1+d)^i}\right]\right) / \left(\sum_{i=0}^{T}\left[\frac{E_i}{(1+d)^1}\right]\right) \quad (11)$$

NPC is defined as the present value of the total cost of the system throughout the Project lifetime minus the present value of the total revenue during the project lifetime.

$$NPC=\frac{C_{ann,tot}}{CRF(i,R_{proj})} \quad (12)$$

$$CRF_{(i,N)}=i(1+i)^n/((1+i)^{(n-1)} \quad (13)$$

Mathematical modelling of the proposed system

The payback period indicates that the project will be profitable on completion of the payback period, EPP can be calculated using equation:

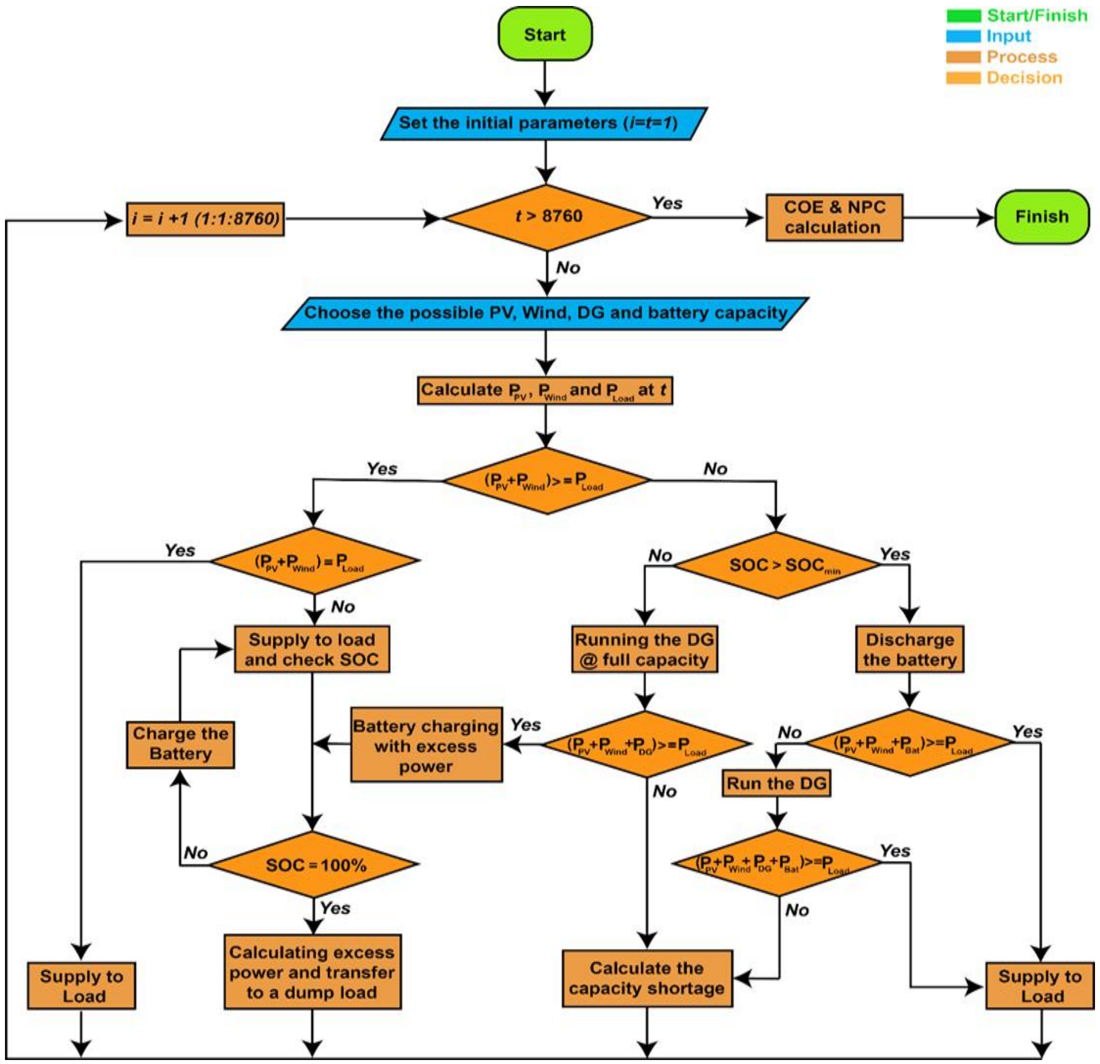
$$\boldsymbol{EPP = \frac{\sum C_c + C_{O\&M} + C_{Rep}}{C_{cashflow}}} \qquad \textbf{(14)}$$

C_c indicates the capital cost, $C_{O\&M}$ operation and maintenance cost.

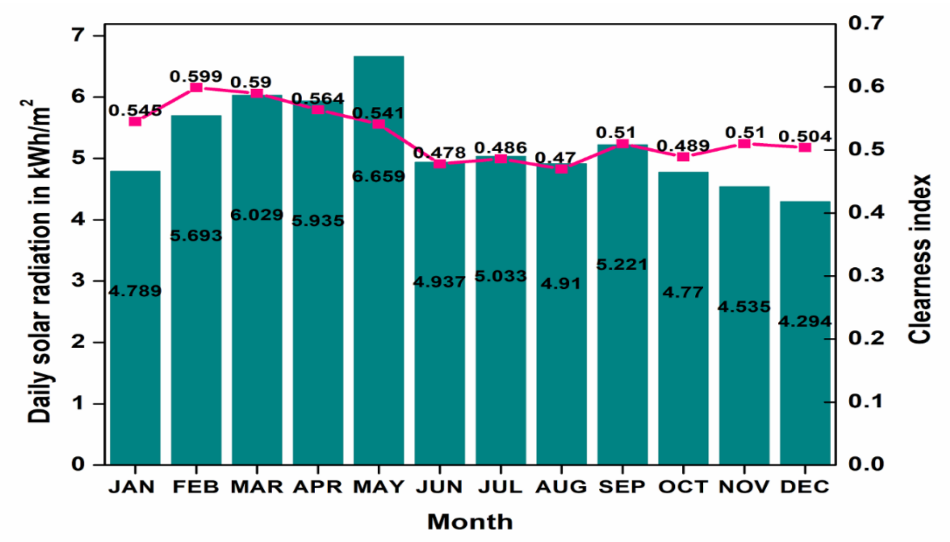
PI can be calculated by using equation:

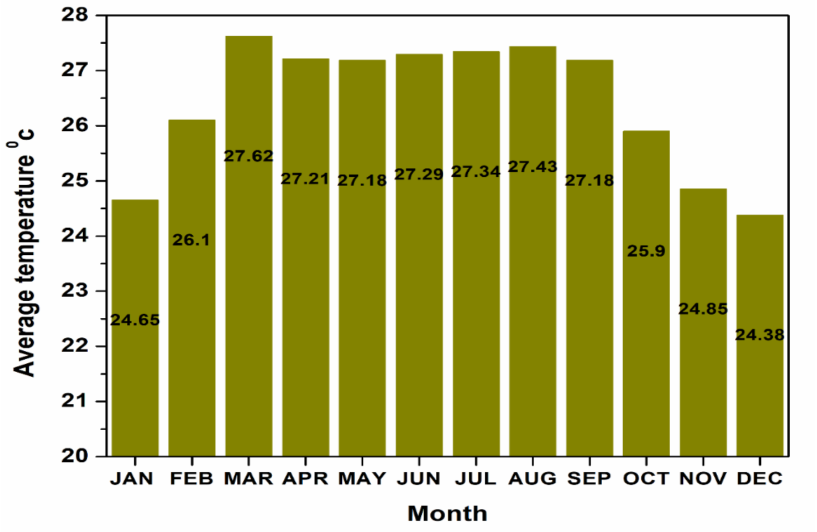
$$\textbf{LCOE} = \left(\sum_{i=0}^{T}\left[\frac{C_i + L_i + O\ \&\ M_i + I_i}{(1+d)^i}\right]\right) / \left(\sum_{i=0}^{T}\left[\frac{E_i}{(1+d)^1}\right]\right) \qquad \textbf{(15)}$$

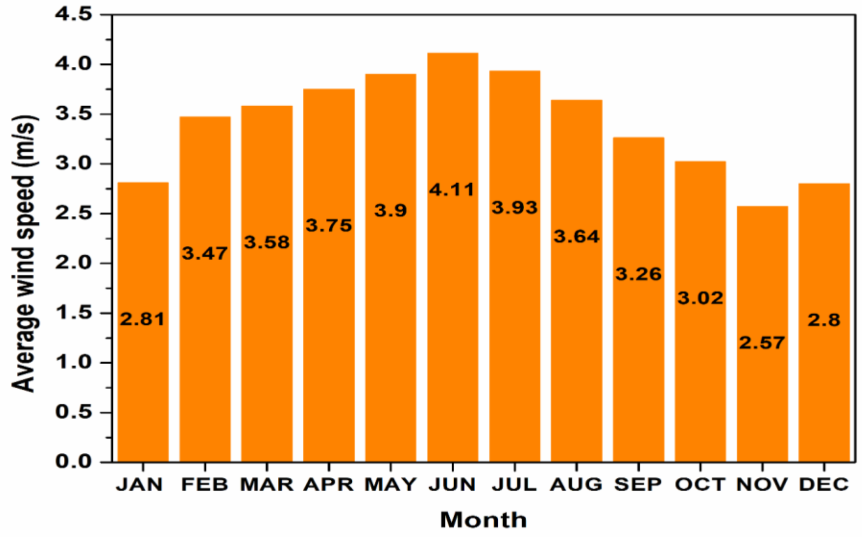
Flowchart of the optimization algorithm performed in HOMER software



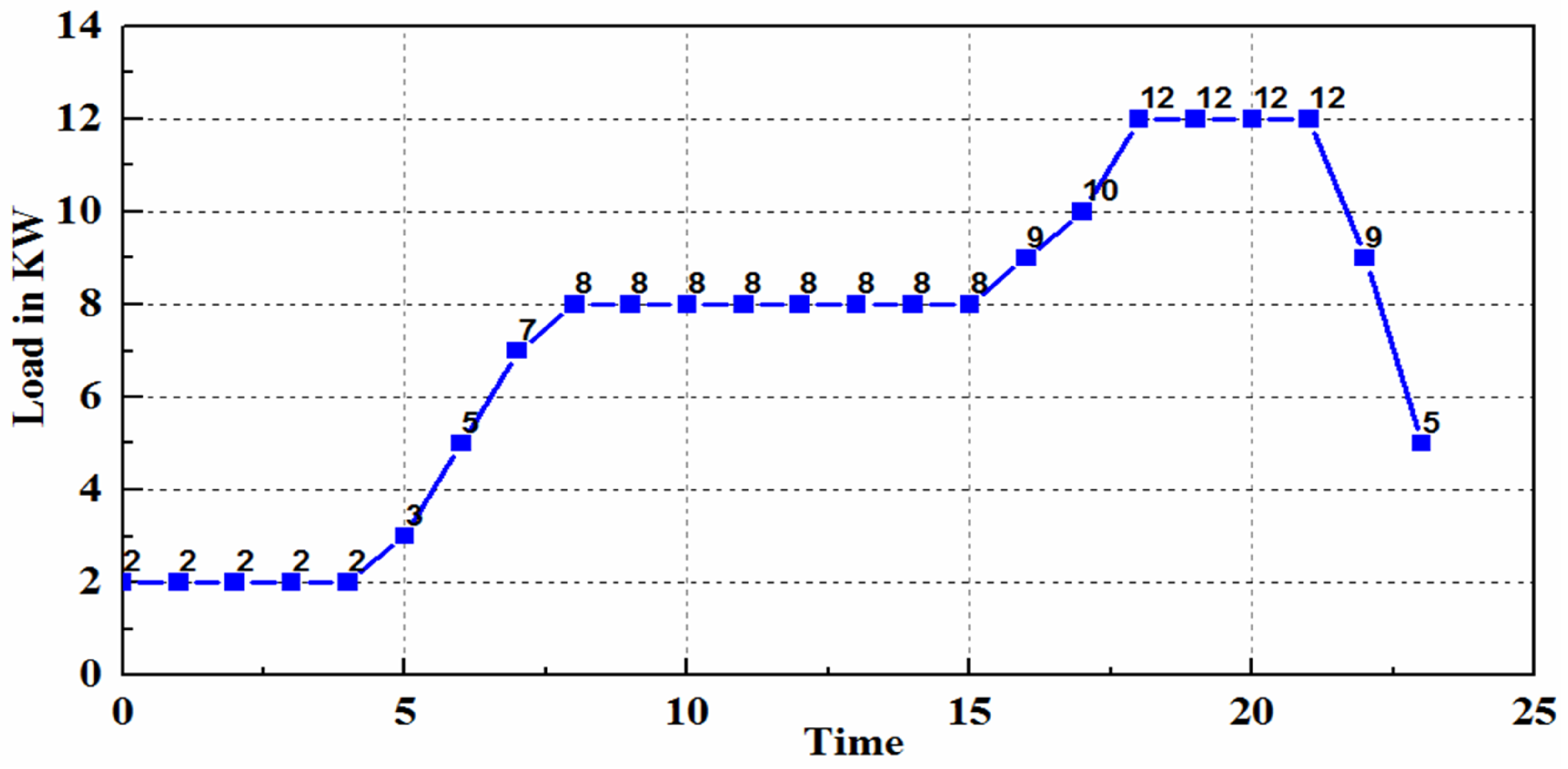
Resource utilization and selection of components





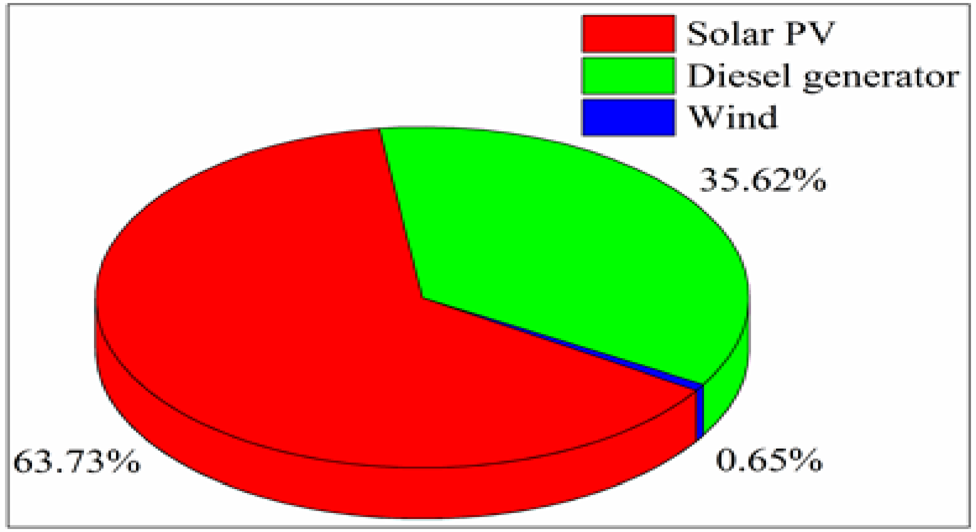


Load curve

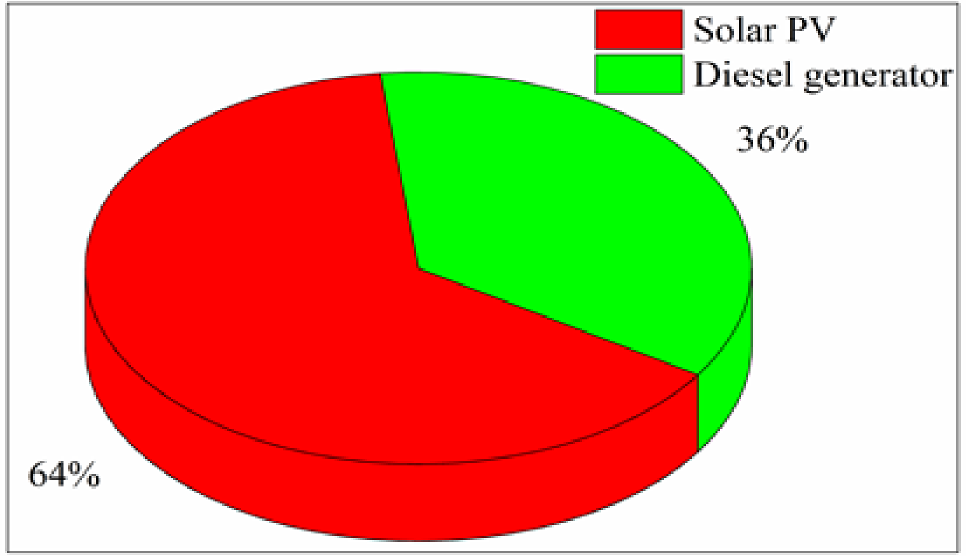


Load in KW
Time
0
2
4
6
8
10
12
14
0
5
10
15
20
25
2 2 2 2 2 3 5 7 8 8 8 8 8 8 8 8 9 10 12 12 12 12 9 5

Autonomous mode



Case-1, when solar, wind and DGs are active

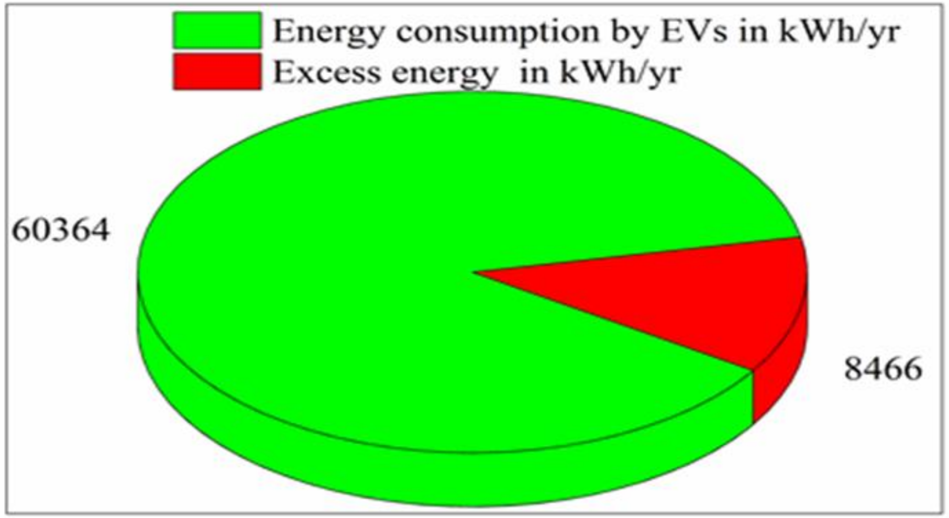


Case-2, when solar and DGs are active

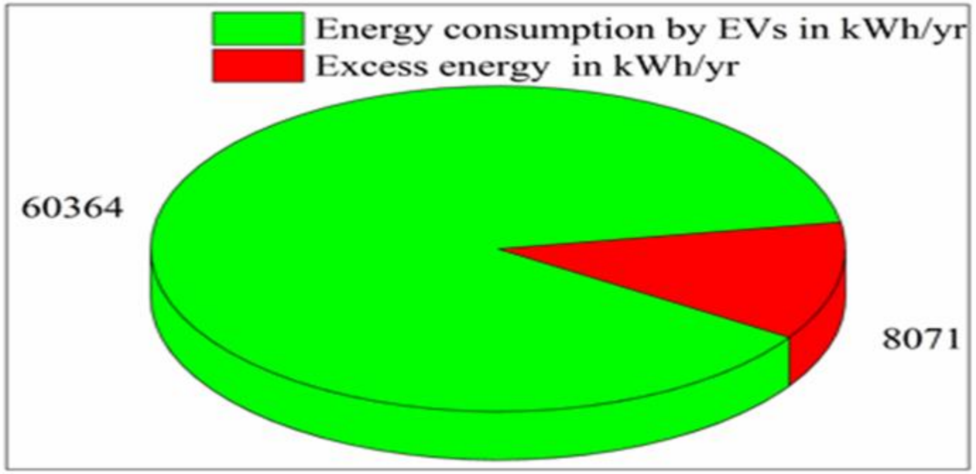
Comparison of case-1 and case-2

Case study	Active Sources	Sizing of the sources	LCOE in $	NPC in $	OC in $	Initial cost in $	Payback period	PI
Case-1	Solar PV+DG+Wind	Solar PV-30KW DG-10KW Wind-3KW LA-147 string	0.336	5,06,503	16,173	1,02,181	4.418	>1
Case-2	Solar PV+DG	Solar PV-30KW DG-10KW LA-152 String	**0.320**	**4,83,115**	**15,893**	**85,668**	**3.911**	**>1**

Energy consumed by the EVs during the autonomous mode of operation



Case-1, when solar, wind and DGs are active

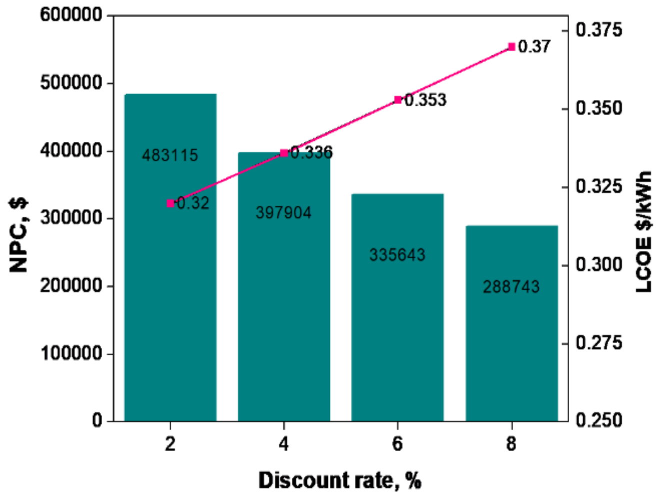


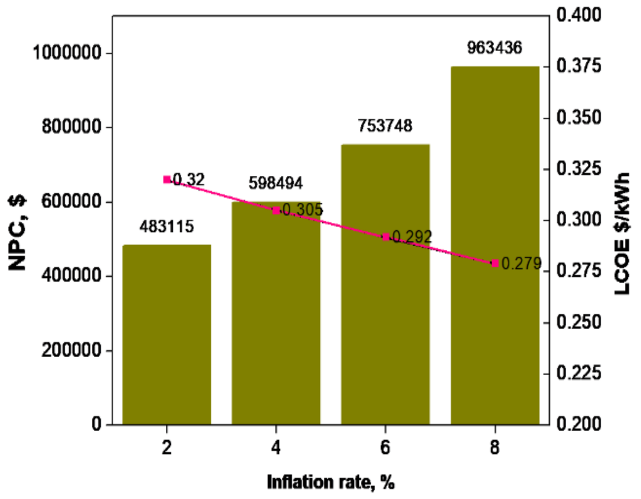
Case-2, when solar and DGs are active

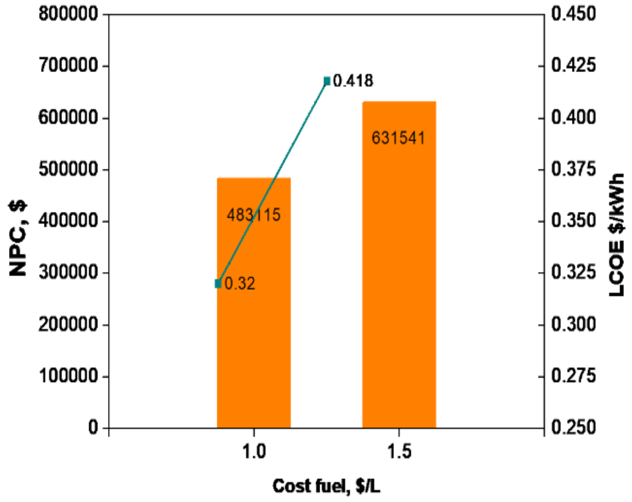
Sensitivity analysis of system

Uncertainty is one of the essential parameters that must be considered while designing any type of Mini-grid or EVCS.

Variation of **discount rate**, inflation rate and **cost of fuel** is considered to **analyze the variation of NPC and LCOE**.







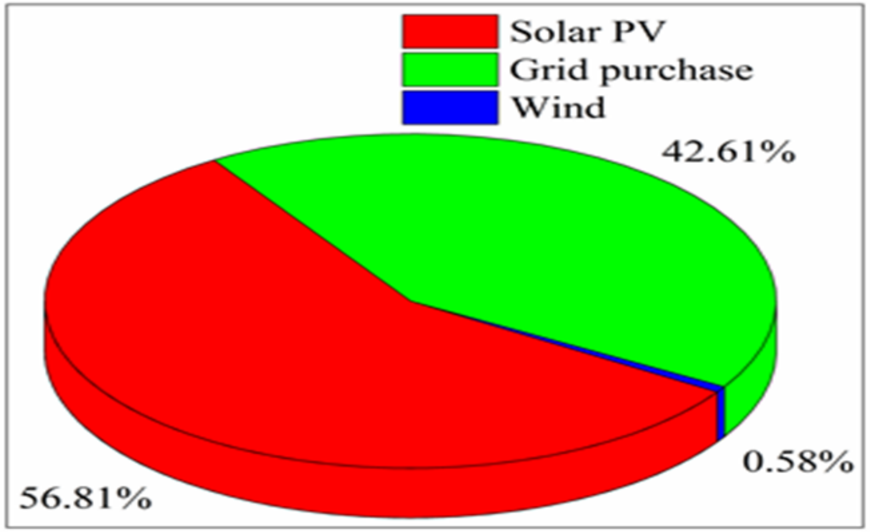
Summary of EVCS cost in autonomous mode (when solar PV and DG are active)

Component	Capital Cost in $	Replacement in $	O&M in $	Fuel cost in $	Salvage cost in $	Total in $
Generator 10kW	2780	16680	30840	234339.49	(407.73)	284231.76
Solar PV 30 kW	36000	0	7500	0	0	43500
Battery 1kWh (152 numbers)	45600	91200	38000	0	(22636.64)	152163.36
Power modulator	1287..86	2575.73	0	0	(643.93)	3219.66
System	85667.86	110455.73	76340	234339.49	(23688.31)	**4,83,114.78**

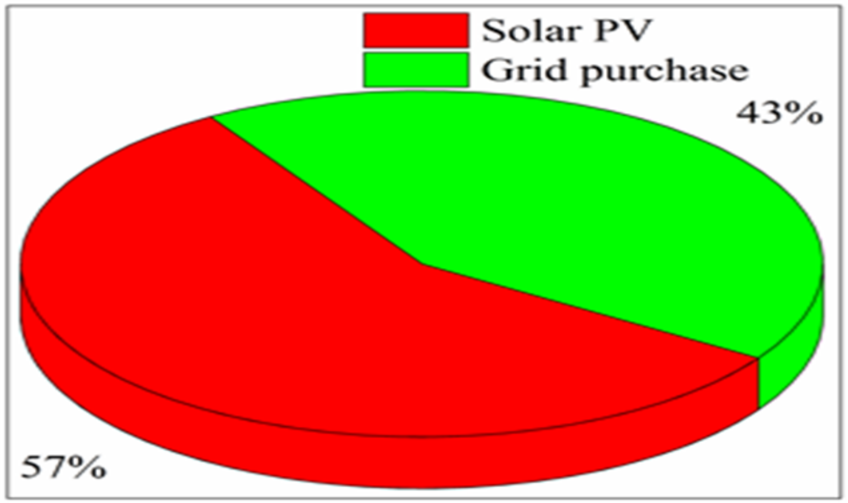
Summary of EVCS cost in autonomous mode (when solar PV, wind and DG are active)

Component	Capital Cost in $	Replacement Cost in $	O&M in $	Fuel cost in $	Salvage cost in $	Total in $
Generator 10kW	2780	16680	30817.50	233456.08	(421.63)	283311.95
Solar PV 30 kW	36000	0	7500	0	0	43500
Wind 3KW	18000	18000	4500	0	(13500)	27000
Battery 1kWh (147 numbers)	44100	88200	36750	0	(19610.22)	149439.78
Power modulator	1300	2601	0	0	(650.25)	3251.25
System	102180.5	125481	79567.50	233456.0	(34182.11)	**5,06,502.97**

Grid-connected mode of operation



Case-1, when solar and wind are active



Case-2, when solar alone is active

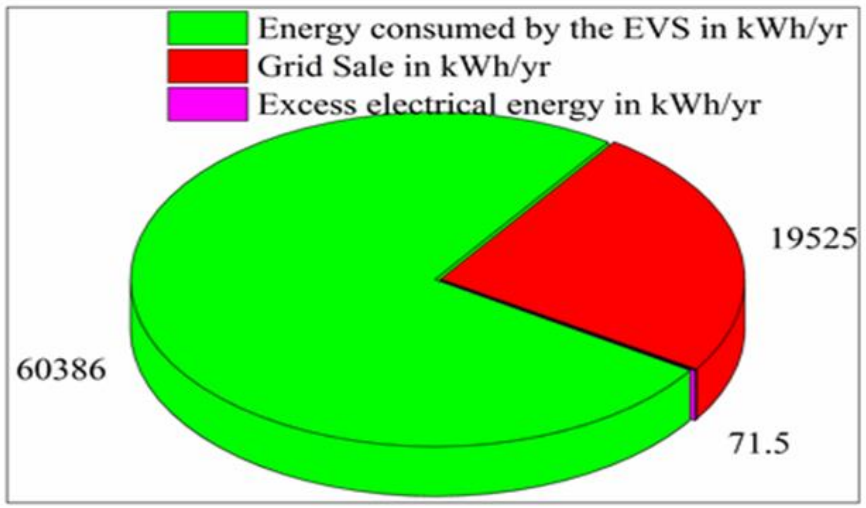
Energy produced and energy sold to the grid when both solar PV and DG are active

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Energy charges ($)
JAN	3,067	1,758	1,310	$43.11
FEB	2,465	1,970	495	-$49.02
MAR	2,765	2,344	421	-$75.06
APR	2,718	1,859	858	-$7.11
MAY	2,741	1,755	987	$10.93
JUN	2,811	1,364	1,448	$76.58
JUL	2,891	1,328	1,563	$89.85
AUG	3,072	1,441	1,630	$90.96
SEP	2,881	1,681	1,200	$35.97
OCT	2,928	1,349	1,579	$90.46
NOV	3,107	1,286	1,821	$117.73
DEC	3,123	1,390	1,733	$103.78
Annual	**34,569**	**19,525**	**15,044**	**$528.17**

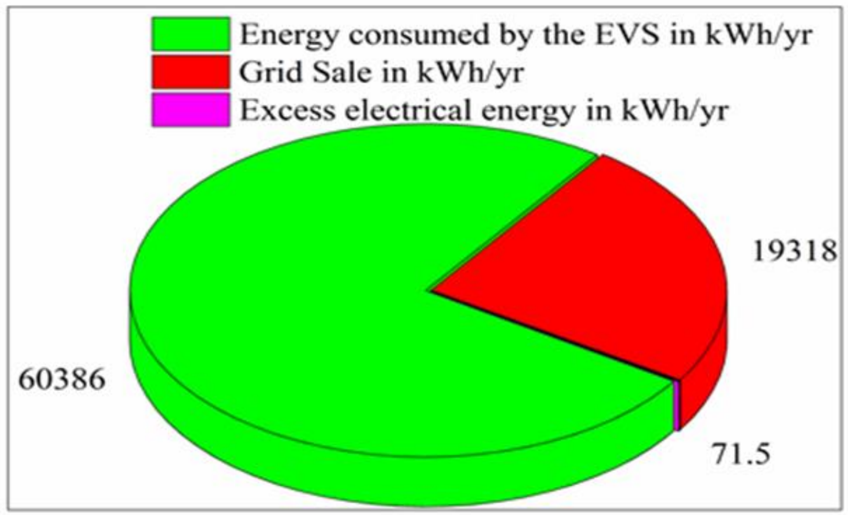
Energy produced and energy sold to the grid when solar PV, wind and DG are active

Month	Energy purchased (kWh)	Energy sold (kWh)	Net energy purchased (kWh)	Energy charges ($)
JAN	3,076	1,752	1,324	$44.80
FEB	2,481	1,951	530	-$44.56
MAR	2,788	2,323	465	-$69.59
APR	2,739	1,829	910	-$0.416
MAY	2,780	1,729	1,051	$18.60
JUN	2,862	1,336	1,525	$85.72
JUL	2,929	1,301	1,628	$97.71
AUG	3,097	1,419	1,678	$96.82
SEP	2,895	1,667	1,228	$39.47
OCT	2,940	1,341	1,599	$92.83
NOV	3,112	1,283	1,829	$118.78
DEC	3,133	1,386	1,747	$105.36
Annual	34,831	19,318	15,514	$585.51

Energy consumed by EVs and grid export



Case-1, when solar and wind are active



Case-2, when solar alone is active

Cost variation by varying the system architecture

Architecture of the system	NPC in $	COE in $	Operating cost in $	Initial capital in $
Case-1 Solar PV-Wind-Grid	90,041.5	0.045	1340.26	56,535
Case-2 Solar PV-Grid	**64,475.09**	**0.03236**	**1037.61**	**38,535**

Summary of the proposed system cost (solar PV is active)

Components	**Capital cost in ($)**	**Replacement cost in ($)**	**O&M cost in ($)**	**Salvage cost in ($)**	**Total ($)**
Converter	2534.90	5069.79	0	(1267.45)	6337.24
Solar PV	36000	0	7500	0	43,500
Grid	0	0	14637.84	0	14,637.84
System	38534.90	5069.79	22137.4	(1267.45)	64,475.80

Summary of the proposed system cost (when solar PV and wind are active)

Components	Capital ($)	Replacement ($)	O& M ($)	Salvage($)	Total ($)
Converter	2534.90	5069.79	0	(1267.45)	6337.24
Solar PV	36,000	0	7500	0	43,500
Grid	0	0	13,204.26	0	13,204.26
Wind	18,000	18,000	4500	(13500)	27,000
System	56,534.90	23,069.79	25,204.26	14,767.45	90,041.50

Greenhouse gases (GHG) mitigation

- **One kWh of electricity generation** from **thermal power plants** produces an average of **980g carbon dioxide**,**1.24g sulphur dioxide**, **2.59g nitrogen oxide** and **68g ash**.
- **Generating adequate power from hybrid renewable sources reduces GHG emissions into the environment and can minimize environmental hazards, including global warming, ozone layer depletion, etc.**
- GHG mitigation for the autonomous and grid connected mode of operation is calculated when only solar is active (best optimum result case is considered) is resultant of **45,172.12kg of CO_2, 57.15kg of SO_2 and 119.38kg of NO_X**.

Comparison of the present system with the existing literature

Type of Hybrid energy sources	LCOE in $/kWh	NPC in $	Initial cost in $	Mode of operation	Reference
PV+Wind+DG + Battery	0.382	8.65 million	880103	Autonmous	[18]
Wind+DG+Battery	0.396	8.97 million	804750	Autonomous	[18]
PV+Biomass	0.349	6,09,524	----	Autonomous	[17]
PV+Biomass+DG	0.366	6,39,796	-----	Autonomous	[17]
PV+Biomass	0.118	2,05,499	-----	Grid connceted mode	[17]
PV+Wind+DG	0.336	5,06,503	1,02,181	Autonomous	Present system
PV+DG	**0.326**	**4,83,115**	**85,668**	**Autonomous**	**Present system**
PV+Wind+Grid	**0.045**	**90,041.5**	**56,535**	**Grid connceted mode**	**Present system**
PV+Grid	0.0323	6,44,75.09	38,535	Grid-connected mode	Present system

Conclusion

- The proposed EVCS is **mathematically modeled, simulated, and the techno-economic performance of the charging station is assessed**.
- The EVCS is designed for both **grid-connected mode and autonomous mode** of operation, and the optimum result obtained is presented.
- In the autonomous mode, the LCOE, NPC and operating cost is estimated at **0.326 $/kWh, $4,83,115 and $85,668,** while in grid connected mode LCOE, NPC and operating cost is estimated at **0.0323 $/kWh, $64,475.09 and $38,535 (when Solar PV, DG and Grid is considered)**.
- The **optimum sizing of the sources** and **energy produced to charge the EVs** is elaborated by **considering different case studies.**
- The amount of **GHG mitigation is significantly high by using a hybrid energy system.**
- A **significant increase** in fuel cost is observed from the past few years, and the usage of electric vehicles is also increasing in all parts of the country; it is very much necessary to develop EVCS for ensuring **energy security** in India.

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Thank you