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Optimal Techno-Commercial Analysis on Electricity Consumption of Industry by Grid Integrated Hybrid Power System

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Abstract

This paper presents modeling, simulation, optimization and sensitivity analysis of renewable energy-based hybrid power system in confectionery product manufacturing industry.Two different models configured by considering grid/PV/diesel generator as model-I and grid/PV/BESS/diesel generator as model-II for particular industry site.Homer grid software tool is used for simulation optimization analysis by investigating techno-economic and environment performance of proposed system.The optimal simulations results reveal that hybrid model with BESS feasible techno commercially with total annualized cost (TAC) and levelized cost of energy (LCOE) NRs.1,10,38,088 and NRs.9.23/KW hr respectively.The optimal designed components added with existing grid transformer 630 kva, diesel generator 580kva are PV rated size 316kW,use able BESS nominal capacity 326 KW hr and hybrid converter size 293kW with inverting/rectification operation time 76 and 24% respectively. Different sensitivity variables considered as grid interruption frequency/duration, renewable energy fraction (REF),battery state of charge (SOC), and autonomy hour to make model selection decision.Financially model accepted with simple payback period (SPP) and discounted payback period (DPP) 1.7 year and 1.9 year respectively with return on investment (ROI) 49.4%, Internal rate of return (IRR) 57.8%. From an environment point of view, hybrid model with BESS showing best performance with total carbon emission saving 135114.7kg/year equivalent to 23.21%.The paper highlight significant role of battery-based PV hybrid renewable energy system (HRES) to deliver reliable electricity supply in product manufacturing industry by considering quality power, plant productivity and product waste recovery.

Keywords

Total annualized cost, levelized cost of energy, renewable energy fraction, state of charge, hybrid renewable energy system

1. Introduction

Progressive energy demand growth and rapid depletion of fossil fuels have raised concerns of future energy supplies[1].Now days,time of modernized and industrial economic development,electrical energy plays vital role.Energy consumption is increasing with increasing industrialization of world similar in Nepal.A study in[2] proved that harvesting solar and wind energies instead of fossil fuel can provide more realistic,competitive,and profitable.As Nepal already on the way of industrial revolution exponentially, then every manufacturing industry keeping their backup power plan unlike renewable energy resources (RES) commonly uses conventional diesel generator.The total diesel imports on fiscal year 2076/77 found 1473,536 KL equivalent to NRs.85.82 billion money value with 7.30% import Share.The carbon dioxide emissions per capita of Nepal increased from 0.02 tons per capita in 1970 to 0.5 tons per capita in 2019 growing at an average annual rate of 7.86%.The world atmospheric Carbon dioxide concentration has increase by approximately 40% by industrial revolution[3].This problem can be overcome by integrating different energy sources with grid to produce HRES such as Photo voltaic (PV), Battery energy storage system (BESS) which produces better environment friendly clean energy.However,the main disadvantage of using RE sources for electricity generation is low reliability due to their intermittent nature.This drawback generally requires over sizing of the system and use of large capacities of energy storage devices,resulting in significant investment cost[4].The correct energy management strategy able to improve power stability, ensure zero power failure, minimize COE,and protect equipment against damage due to overloads.Nepal has still less efficient, high loss distribution system bear up to 70% loss of total electricity loss.Due to frequent power failure of grid line, grid power utilization of manufacturing industry still below 90%.So, industries are seeking best power solution with zero failure.Main scope is optimized operation of DG by hybrid configuration of PV and BESS is ability to switch off the DG in presence of PV and shifted load automatically from one to other component then fuel cost ultimately reducing the manufacturing cost of product along with low maintenance cost as compared to operation of DG. However, the uncertainty on output power generation of renewable energy sources due to geographical location of site, solar radiation variation on weather and temperature is the main limitation of this model.Also high investment cost associated with the battery for less life cycle maximum 5 years is limited up to certain minutes backup.The authors in[5] investigated the best energy management strategy for HES in three different places in India and found that the load following(LF) strategy achieved better techno-economic and environmental performance than the cycle charging(CC) dispatch strategy for all locations.Azerefegn TM,Bhandari R,Ramayya AV highlighted in[6] as the techno-economic feasibility analysis of grid-tied PV power system is investigated under unscheduled grid outage consideration and found that grid/diesel/PV/battery systems are technically,economically,and environmentally feasible for all three climate regions with the cost of energy at 0.044, 0.049,& 0.048$/KWhr respectively.

2. Methodology

2.1 Problem formulation

The Hybrid model of electrical optimization includes objective function, decision variable and constraints. The main aim of hybrid system is to minimize the annual energy cost i.e. total annualized cost(TAC) of system.

$$F_{\min} = TAC_{\min}\left(N_{pV}, N_B, PN_{inv}, PN_{dg}\right) \tag{1}$$

$$= \sum_{K=pV,B,inv,dg} \left(C_K + 0\&M_K + R_K + FC_K - S_K\right) \tag{2}$$

Where C,O&M,R,FC,and S are annual equivalent cash flow of capital, operation and maintenance, replacement, fuel cost and salvage value of each component(K) respectively.The equivalent annuity is obtained by multiplying the present worth and capital recovery factor (CRF).

$$\mathrm{CRF}(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{3}$$

Where i & n are interest rate typical 10% and life span of the system typical 25 years.

$$= CRF(i,n)\left\{C_{PV}N_{PV} + C_B N_B + C_{dg}N_{dg} + C_{inv}N_{inv}\right\} \tag{4}$$

Where C_{PV},C_B,C_{inv},C_{dg} are are installation cost per unit PV module,battery,converter,and installation cost per KW of diesel generator respectively.The operational and maintenance of battery and inverter are ignoring due to negligible amount on account.

$$\sum_{K=PV,dg} O\&M_K$$

$$= O\&M_{PV}N_{PV} + O\&M_{inv}N_{inv} + O\&M_{dg}\sum_{t=1}^{8760} P_{dg}(t) \tag{5}$$

Where $O\&M_{PV}$,$O\&M_{inv}$,$O\&M_{dg}$ are operation and maintenance cost of one unit of PV module, Inverter and diesel generator per KWhr respectively. P_{dg}(t) is power from diesel generator t.During life time of system, only batteries are replaced in 5^{th},10^{th},15^{th},20^{th} year.

$$\sum_{K=B,dg,inv} R_K$$

$$= CRF(i,n)\left\{R_B N_B\left(\frac{1}{(1+i)^5} + \cdots + \frac{1}{(1+i)^{20}}\right)\right\} \tag{6}$$

Where R_B are replacement cost of battery.The salvage value of component is its remaining value at end of the project lifetime.

$$S_K = C_K\frac{t_t}{n} \tag{7}$$

Where C_K, t_t are installation or replacement cost of component and remaining time of component.The PV component only has salvage value at the end of project life time for proposed hybrid system.The levelized cost of energy (COE) is the average production cost of one unit useful power by the system.

$$COE = \frac{TAC}{E_{Serv}} \tag{8}$$

Where E_{Serv}=E_{grid}+E_{HES} is useful power served from system.

2.1.1 Decision Variable

- Number of PV modules(N_{PV})
- Number of Batteries(N_B)
- Normalized power of inverter(PN_{inv})
- Rated capacity of diesel generator (PN_{dg})

2.1.2 Constraints

- Variable type constraint N_K=Integer $K \in (PV,B)$
- Bound constraint

$$\begin{aligned} &0 \leq N_K \leq) N_{K_{Max}} K \in (PV,B) \\ &0 \leq PN_{inv} \leq PN_{inv_{Max}} \\ &0 \leq PN_{dg} \leq PN_{dg_{Max}} \end{aligned}$$

Where $N_{K_{Max}}$,$PN_{inv_{Max}}$,$PN_{dg_{Max}}$ are maximum number of components, allowable capacity of inverter and generator.

- The renewable energy fraction constraint limits the proportion of non-renewable energy.REF=

$$\left(\frac{1 - \sum_{t=1}^{8760} P_{dg}(t)}{\sum_{t=1}^{8760} P_l(t)} \right) * 100 \geq REF^*$$

where REF^* is the minimum allowable REF.

2.1.3 Objective Function

$F_{\min}$=$TAC_{\min}\left(N_{pV}, N_B, PN_{inv}, PN_{dg}\right)$ =

$$\sum_{K=pV,B,inv,dg} (C_K + 0\&M_K + R_K + FC_K - S_K)$$

$$\text{S.t} \begin{cases} N_K = \text{ Integer }, K \in (PV,B) \\ 0 \leq N_K \leq) N_{K_{Max}}, K \in (PV,B) \\ 0 \leq PN_{\text{inv}} \leq PN_{\text{inv}\ Max} \\ 0 \leq PN_{dg} \leq PN_{dg_{Max'}}, REF \geq REF^* \end{cases}$$

2.2 Flowchart for Optimization

The proposed HES system is connected main grid line to supply load demand. There are different combined cases to find minimum TAC that includes current grid and diesel generator, RES with PV only, combination of grid connected RES with PV and BESS. The Hybrid Optimization Model for Electric Renewable (HOMER) software use for optimization and sensitivity analysis.

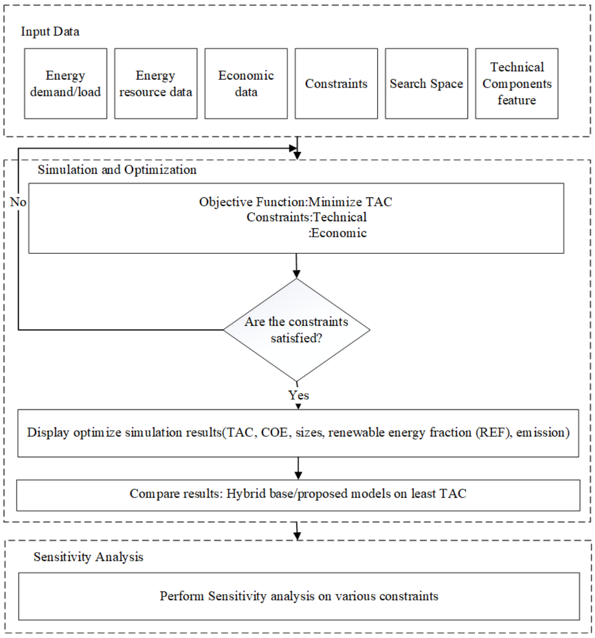

Figure 1: A flowchart for optimization

2.3 Modeling and Simulation on Homer Grid

Modeling of the economic viability of HRES, the climatic data for the respective regions and load to be supplied was considered.These will enable adequate sizing of solar panels, converters,batteries as well as the capacity of diesel generator.Consequently,the feasibility of meeting load demand will be easily determined based on the installation, replacement, operational,fuel cost,interest rate,and other constraints.

2.3.1 Site location and Case study

The case study performed on confectionery food manufacturing industry called Sujal Foods Pvt. Ltd which is leading confectionery food production industry in Nepal by volume located at pokhara with latitude 28 degrees 12.57 minutes N,longitude 83 degrees 59.13 minutes E on warm and temperature climate.Industry found connected 11 KV NEA grid line in name of Lekhnath-Budhibazar feeder.

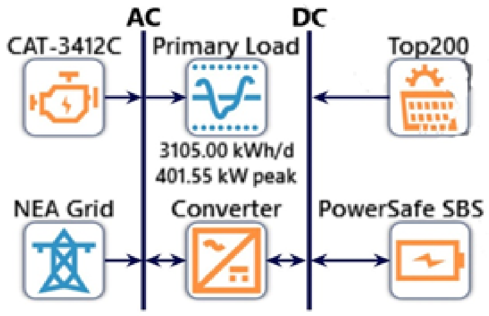

Figure 2: Hybrid system modeling

2.3.2 Load profile and data collection

In this research thesis work, the electrical load of above mention industry selected to carry out the techno economic analysis.The load data taken on the basis of yearly (FY-2020/2021) energy report SFPL2/Eng./F/007 of this company.The measured estimated scale daily electricity consumption of this manufacturing industry found 3105 KWhr,peak load 401.55 kW with load factor 0.32.

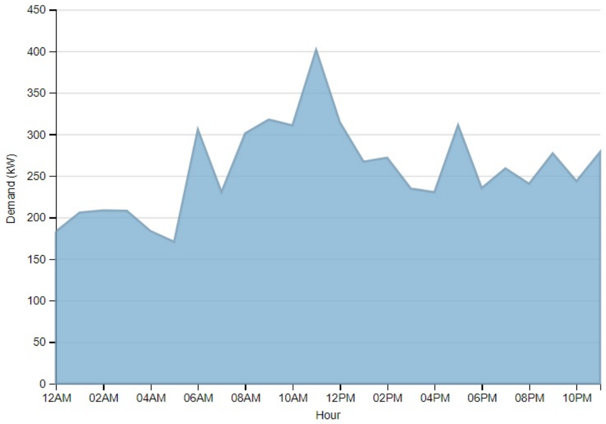

Figure 3: Load profile at peak demand

2.3.3 Resource Assessment

According to Karkee, Rijan, et al.[7] monthly daily solar radiation 5.13 KWhr/m2/day on case study site location. In order to determine the actual power from solar PV, ambient temperature of site is very important. The avg. temperature of site is 13.9 °C.

2.3.4 Electricity Tariff and Grid Outage

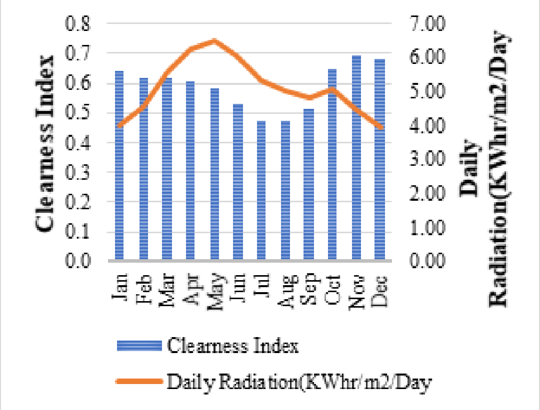

Figure 4: Monthly avg. solar radiation on site

Table 1: Grid outage frequency and duration

Name of feeder	Budhibazar(11KV)
Interrupt frequency (Int/year)	750
Interrupt duration(hr./year)	112.5
Mean repair time(hr.)	0.15
Repair time variability (%)	5

In order to design reliable electricity system with optimum size of hybrid distributed generation,exact value of unreliable grid interruption is very important.From recorded data investigation of Lekhnath-Budhibazar feeder,the line interruption duration and frequency of industry found as per below.The repair time variability during modeling taken as 5% from data keeping record of NEA gird energy report.

3. Results and discussions

In this research, the proposed system configurations considered with PV on existing system and with PV and BESS with existing system in name of model-I and Model-II.To select most techno-economic practicable system configuration,necessary performance factors and sensitivity variables are considered.

3.1 Optimum System Configuration

The loads and the main grid are connected to the AC bus.A bidirectional power converter ties the DC bus to the AC bus for bidirectional energy transfer.

3.1.1 Optimum Grid Performance

The grid performance in sense of electricity purchase drastically decreased on both feasible configuration model with 53.1% and 56.0% with increase grid sales 3.5% to 4.9% on model I & II respectively.Electricity generation from diesel generator on economic model-II drastically reduced near to zero which value share by grid and RES.

Table 2: Optimum grid utilization on model-I&II

Parameter	Model Configuration	
	Model I	Model II
Transformer (KVA)	630.0	630.0
Purchase (MWhr/year)	694.2	689.7
Purchase (%)	53.1	56.0
Sales (MWhr/year)	40.7	58.5
Sales (%)	3.5	4.9

Table 3: PV generation with grid integration

Parameter	Model Configuration	
	Model I	Model II
Operation hours/year	4380	4380
Rated capacity (kW)	259	316
Mean output (kW)	49.8	60.7
Generation (MWhr/year)	436.1	531.6
Mean output (KWhr/day)	1195	1456
Capacity factor (%)	19.2	19.2
Electrical production (%)	33.4	43.2
Maximum output (kW)	246	300
PV penetration (%)	38.5	46.9
LCOE (Rs./kWhr)	3.76	3.76

3.1.2 Optimum PV Performance

The PV power generation contribution on total electricity consumption of industry 33.4% and 43.2% on Model-I&II.The PV penetration level on proposed model-I&II 38.5% and 46.9% respectively with cost of energy (NRs./kWhr) 3.76.The derating value of solar panel considered 85% with average solar radiation on Pokhara location taken as 5.13 KWhr/m2/day. The power output from Solar PV on both models found mean output power from PV panel 49.8 KW and 60.7 KW on system without battery and with battery respectively.

3.1.3 Optimum Generator (DG) Performance

The operational time of DG per year on model-I is 758 hrs due to lack of online backup after grid failure however PV generation power present but not fully support to meet load demand of grid outage time. After battery placement for with hybrid converter power supply will start from both online PV generation and battery backup as per load following strategy to meet load demand. Due to this number of starts of DG per year drastically reduce to only 44 start/year. Due to this utilization of DG power reduce to almost 0.8% of total electricity consumption of industry with Avg. fuel consumption/day reduce from 144 to 8.4 liter/day.

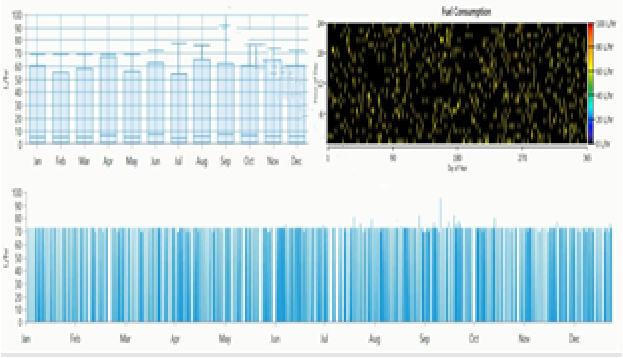

Figure 5: Fuel consumption without BESS

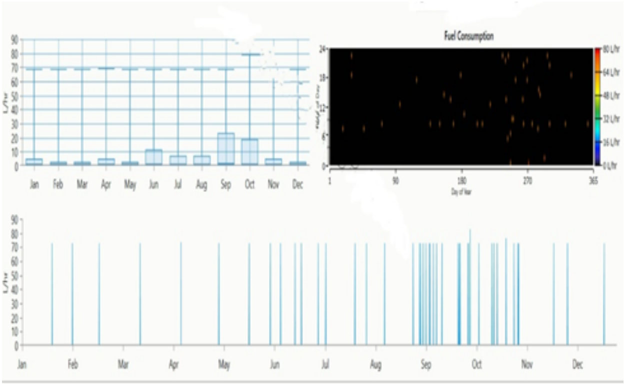

Figure 6: Fuel consumption with BESS

3.1.4 Optimum Performance of BESS

The battery backup for hybrid system with BESS mainly depends on how long grid power interruption with frequency of power failure.The battery autonomy for proposed model calculated 2.52 hours.Battery autonomy hours directly depend upon how much load need to backup during outage of grid and solar power generation.According to load following strategy, battery assumed 100% charging before just outage of power grid.

3.1.5 Optimum Performance of Converter

The operation of converter on Model-I only inversion due to no BESS on this system.The hybrid converter whether its works on charging mode or inverting mode will depends upon battery SOC.If battery SOC less than 40% converter immediate start to operate rectify mode until battery SOC maintain 100% during grid presence.If the grid becomes outage, then both inverting/rectification mode comes in operation simultaneously to meet load demand until grid back to energized with ratio 76% and 24% operational time respectively. Components electricity consumption pattern found as per figure 8 and 9.

Table 4: Optimal performance of BESS

Parameter	Model II
Number of batteries	211
Number of string size	100
Number of strings in parallel	211
Bus voltage (V)	12
Autonomy (hour)	2.52
Storage wear cost (Rs./kWhr)	7.94
Nominal capacity (kWhr)	543
Usable nominal capacity (kWhr)	326
Life time throughput (MWhr)	579.8
Expected life (year)	6.85
Energy input (MWhr/year)	85.9
Energy output (MWhr/year)	83.3
Storage depletion (kWhr/year)	541
Loss (kWhr/year)	2034
Annual throughput (kWhr/year)	84.6

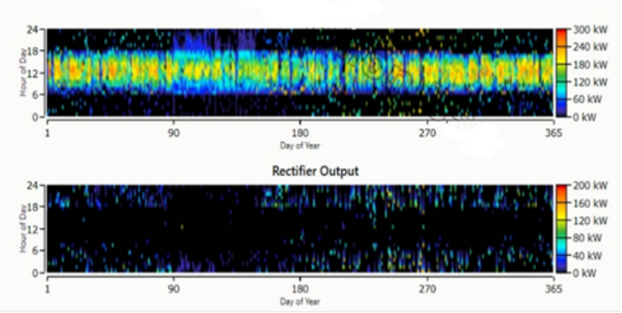

Figure 7: Performance of converter on model-II

3.2 Financial Analysis

The total annualized cost (TAC) for hybrid system without BESS NRs.14350399.00 with cost of energy per unit NRs.12.23.Similarly,annualized cost (TAC) with BESS found NRs.11038088 with COE NRs.9.23.It was noted that the diesel generator component represented about 38% of the TAC of the system on hybrid model-I similarly only 5% cost contribution on hybrid model-II. The return on investment (ROI) on proposed model found as 49.4% on time period of 25-year project lifetime known as profitability of investment.Similarly, the internal rate of return (IRR) of proposed model found 57.8% that means estimate profitability of a potential investment discounting also known as cash flow which gives a ROR earned by a project.

3.3 Sensitivity Analysis

Sensitivity analysis of an HRES is necessary to comprehend the system behavior with changes in the availability and parameters of various RES in the selected site area.Sensitivity analysis indicates the effect of changing multiple values for a particular input variable on the optimal system design.The varied parameters of this study are:Impact of grid outage frequency,level of RE penetration,state of battery charge (SOC) to identify impact on cost of energy.

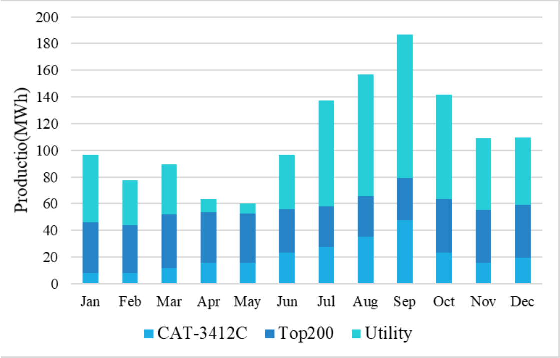

Figure 8: Electricity unit utilization on model-I

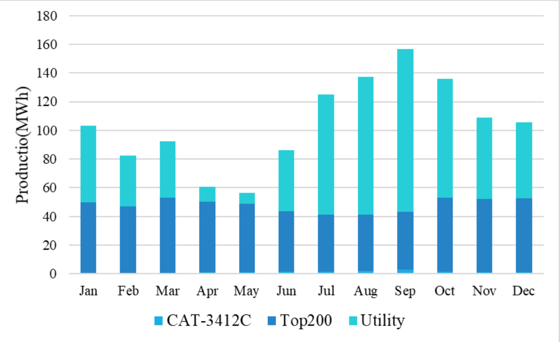

Figure 9: Electricity unit utilization on model-II

3.3.1 Impact of Grid Outage Frequency

By keeping the total load and the grid power price constant,the line interruption duration of grid was varied from 250-1050 frequency/year,COE increased

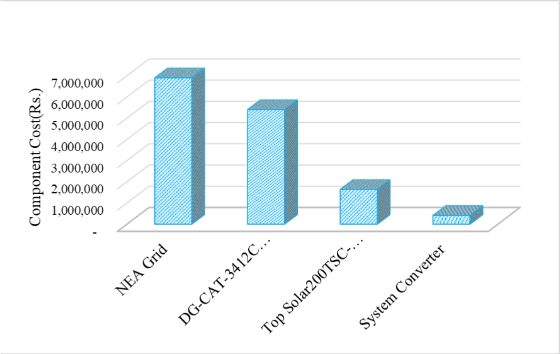

Figure 10: Annual Component cost of model-I

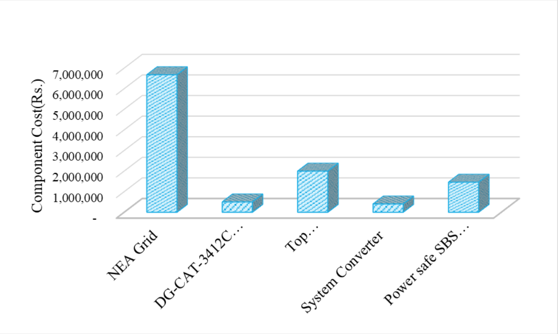

Figure 11: Annual Component cost of model-II

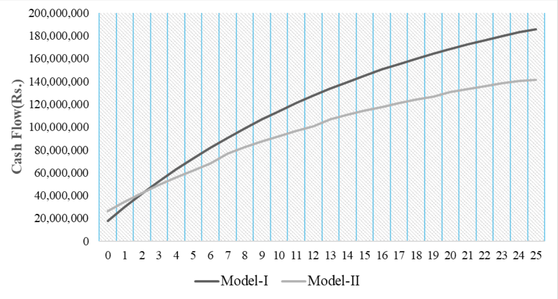

Figure 12: Cumulative Cash flow of project life time

with increasing line interruption frequency.So low frequency outage with limited outage duration up to battery autonomy hours found better to avoid startup operation of diesel generator for every grid outage.

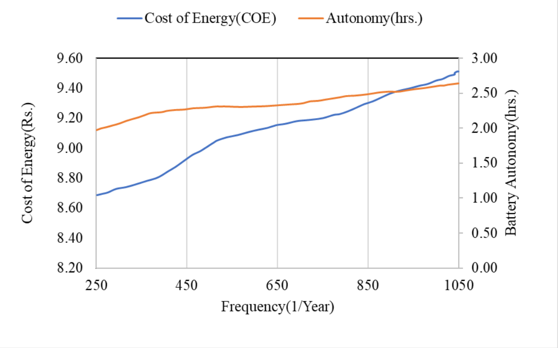

Figure 13: Grid outage on COE/battery autonomy

3.3.2 Impact of Renewable Energy Fraction (REF)

The renewable penetration level on proposed hybrid model indirectly proportional to cost of energy up to certain level.The COE directly proportional to renewable energy fraction from 25% to 60%. Penetration level above 60% also found over investment on renewable source of energy for selected site.Therefore,renewable penetration level swing between 25-60% found effective impact on cost of energy.Therefore 46.9% renewable energy fraction recommend on proposed hybrid model with BESS.

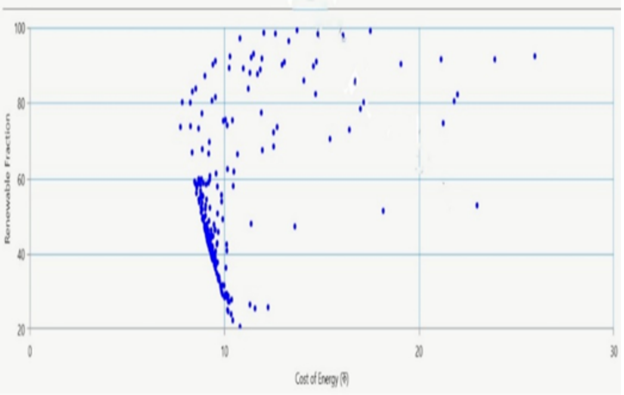

Figure 14: Impact of REF on COE

3.3.3 Impact of Battery State of Charge (SOC)

The impact of the SOC_{min} on the system performance was investigated with variations SOC_{min} found directly proportional to battery SOC_{min} that means if increased in minimum condition of charge of battery,the cost of energy also increases due to extra investment on battery and found economical on between 40-45% for Lithium-ion battery by considering life of battery and its output efficiency. The diesel generator operational hours also depend upon how much battery energy can provide the backup to meet load demand during grid failure also depends upon battery autonomy hours.Therefore,the operation of diesel generator decreases with decreases on battery $SOC_{min\%}$.

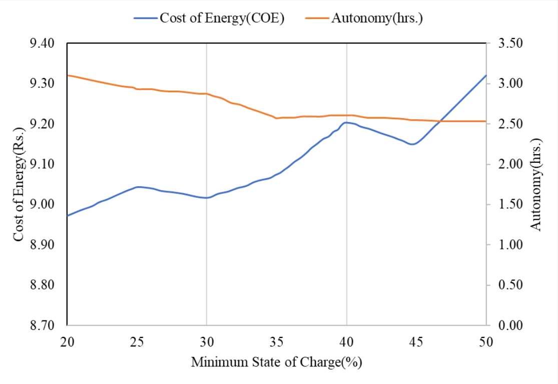

Figure 15: Impact of $SOC_{min\%}$ on COE

3.4 Environment Assessment

The HRES have positive effects on the environment. Combining PV with the diesel and battery is capable of reducing the emissions significantly[8].The carbon emission saving on proposed hybrid model with BESS

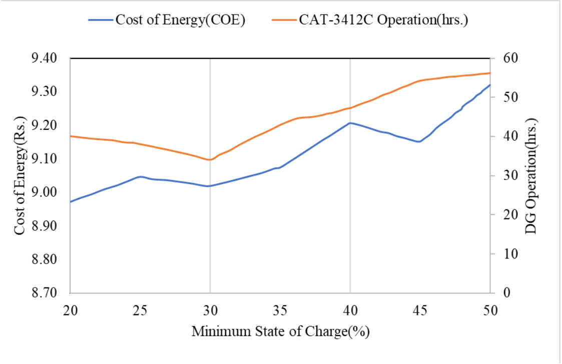

Figure 16: Impact of $SOC_{min\%}$ on DG operation

calculated 135114.7kg equivalent to 23.2% than that of hybrid model without BESS.

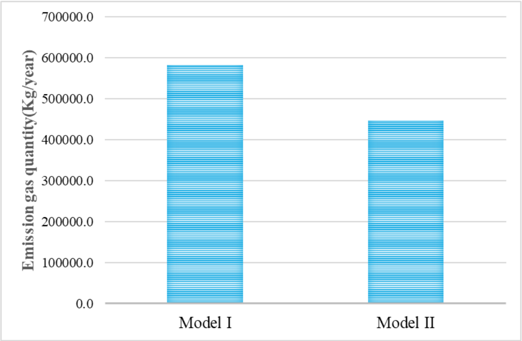

Figure 17: Quantity of gas emission on model-I&II

4. Conclusion

This study presented an optimal RES components added economically in particular manufacturing industry to reduce overall cost of electricity.Two different configurations with existing system have been examined at grid connected hybrid power system.HRES have proposed in industry to improve reliability of power generation and demonstrated the coordinated control of PV, DG and BESS system.The hybrid Homer grid simulation has proved that Grid/PV/BESS/Diesel generator model gives lower COE with reliable power quality supply for selected manufacturing industry.Proposed techno-economic model has provided NRs.9.23/KWhr electricity with 46.9% PV penetrations.Sensitivity analysis showed that cost of energy varied directly with grid power interruptions,battery autonomy also directed with grid failure duration and frequency.Renewable energy fraction level above 60% found over invested and RE penetration swing between 25-60% found effective impact on cost of energy.Similarly,battery SOC increased greater than 40% showing drastically increases cost of energy due to extra investment on battery.The environmental point of view 23.2% emission saving found which directly positive impact on environment.Therefore, battery-based PV hybrid energy system could play an essential role in sustainable electricity supply industries to achieve goal of sustainable development goal $(SDG)_7$ which call for affordable, reliable, sustainable and modern energy for all sector of Nepal.

References

[1] Mohammad Usman, Mohd Tauseef Khan, Ankur Singh Rana, and Sarwar Ali. Techno-economic analysis of hybrid solar-diesel-grid connected power generation system. *Journal of Electrical Systems and Information Technology*, 5(3):653–662, 2018.

[2] YH Ahssein Amran, YH Mugahed Amran, Rayed Alyousef, and Hisham Alabduljabbar. Renewable and sustainable energy production in saudi arabia according to saudi vision 2030; current status and future prospects. *Journal of Cleaner Production*, 247:119602, 2020.

[3] Diana Moreira and José CM Pires. Atmospheric co2 capture by algae: negative carbon dioxide emission path. *Bioresource technology*, 215:371–379, 2016.

[4] Javid Mohtasham. Renewable energies. *Energy Procedia*, 74:1289–1297, 2015.

[5] SK Saraswat and KVS Rao. 10 kw solar photo voltaic—diesel hybrid energy system for different solar zones of india. In *2016 International Conference on Emerging Technological Trends (ICETT)*, pages 1–6. IEEE, 2016.

[6] Tefera Mekonnen Azerefegn, Ramchandra Bhandari, and A Venkata Ramayya. Techno-economic analysis of grid-integrated pv/wind systems for electricity reliability enhancement in ethiopian industrial park. *Sustainable Cities and Society*, 53:101915, 2020.

[7] Rijan Karkee, Sumit Khadka, Gaurav Luitel, Mausham Devkota, Bibek Khadka, Shushilata Sapkota, and Puja Bhetwal. Comparing and optimizing of solar insolation on yearly, monthly and seasonally basis for solar devices performance in nepal. *Int J New Technol Res*, 3, 2017.

[8] H Rezzouk and A Mellit. Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of algeria. *Renewable and Sustainable Energy Reviews*, 43:1134–1150, 2015.