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OPTIMAL ENERGY SAVING FOR MOTORWAY M-2 USING UNRELIABLE GRID TIED-PV DIESEL HYBRID DESIGN SYSTEM

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ABSTRACT: Pakistan, as a developing country is facing serious challenges of energy crises since the last decade due to growth in demand of energy day by day and lack of investment in the appropriate utilization of available energy resources. Due to the adverse environmental impact of Diesel Generators and like Greenhouse Gases (GHG) emission and declining the prices of solar panels, Renewable Energy Resources (RERs) are being increasingly executed due to their eco-friendly, least global warming emissions (GWE) and its least maintenance cost. The research is a study on integration of solar PV generation into the existing unreliable grid-connected system with diesel generators at Motorway Service Area (MSA) Bhera, Punjab, Pakistan. The main objective is an implementation of on-grid photovoltaic-diesel generators hybrid power system to minimize the Net Present Cost (NPC) and Cost of Energy (COE) along with reduction in emission of GHG and the import of fossil fuel used in generation of electricity. Comprehensive economic, technical and environmental analysis is performed through Hybrid Optimization Model for Electric Renewables (HOMER) with five different design systems starting from existing unreliable grid with one large rating diesel generator and later on integration of PV into existing system. NPC and COE are least in proposed system as compared to four other design hybrid systems. NPC and COE of proposed PV-DGs-Grid system are 2.07 M$ and 0.168 $/KWh, respectively with payback period of seven years over the life span of 25-year project. The proposed system is eco-friendly and saves 33% CO_2, 41% CO and 47% Nitrogen Oxides as compared to existing system. The proposed system is implementable on all sites of Motorways in the country with little variation in the design keeping in view the required demand for energy.

Keywords: Diesel Generator (DG), Greenhouse Gases, Global Warming, Hybrid System, Photovoltaic, Renewable Energy Resources, Unreliable Grid.

INTRODUCTION

Pakistan is facing terrific load-shedding since the last decade due to a large power gap between generation and utilization. The economic growth of the country is severely affected by the shortage of energy due to its poorly managed and underdeveloped infrastructure. Solid steps are mandatory to minimize the Transmission & Distribution (T&D) losses with upgrading the T&D infrastructure and pilfering of electricity. This mechanism require a proper understanding and working on the solution of economic dispatch problem (EDP) and meta-heurestic techniques like Particle Swarm Optimization (PSO) that was reviewed in detail (G. Abbas *et al.,* 2017). Alternative Energy Development Board (AEDB) is also trying to promote renewable energy in the country since 2003 to promote distribution generation. It is also planned to supply 40,000 villages that have no direct access with national grid (Shaikh *et al.,* 2013).

Evaluation of grid-tied PV hybrid system carried out to meet the energy demand of household in Jordan (Abujubbeh *et al.,* 2019) and a hybrid system with combination of more than two renewable sources assessed to meet the required energy demand in rural & remote areas (Kundankar *et al.,* 2018). A techno-economic aspect of PV grid-connected system through tracking and penetration of photovoltaic considering the peak load demands of 3040.8 MW by HOMER is evaluated (Ghani and Awasthi*.,* 2017) and hybrid energy system to meet the energy demand of approx. 758 KW are studied through which the simulation result shows that a grid-tied PV system with 18% PV penetration is economical as compared to other cases. Photovoltaic-wind-diesel generator hybrid system for peak demand of 287.38 KW considering three different areas including tropical, Sunny and Windy are scrutinized (Mahmood and Mahmood*,* 2017) and comparison is performed of On-grid and Off-grid Photovoltaic-wind-diesel generator system is carried out through HOMER (Ghose *et al.,* 2017). Multiple paralleled diesel generators are evaluated over single large diesel generator through HOMER (Kusakana, 2017). Hybrid systems with multiple energy sources are simulated to meet the peak load requirement of 4340 kW and to reduce COE and reduction in environmental emission are evaluated (Habib and Mahmood*,* 2017). A grid-connected diesel generator with integration of PV system & battery storage proposed for peak load of 103 KW of Government College of Technology, Muzaffargarh to reduce COE (Sher and Abbas, 2016). The optimal design of a grid-connected diesel PV hybrid system is analyzed, taking the electrical data of 604 customers (Kushida and Abe, 2016). PV-diesel hybrid system evaluated through HOMER for Serbia Island (Wicaksana *et al.* 2016). Evaluation of wind-diesel generator with battery bank backup, Photovoltaic-wind-diesel & diesel generator only examined. A hybrid system with combination of PV & Generator analyzed for remote areas of Indonesia for three different verities of load using. Grid-tied Wind-PV hybrid system evaluated for peak load requirement of 326 KW. A solar-diesel off-grid hybrid system proposed for primary load of 60 KW & deferrable load of irrigation system to take maximum production with lower COE to meet primary and deferrable load requirements. Comparisons of four energy systems are carried out for 10KW hypothetical load including only diesel generator, solar-diesel, and only renewable energy and PV-diesel energy system with battery storage. Analysis of grid-connected PV- diesel hybrid energy system for electrification of industrial areas and three energy systems are analyzed starting from diesel only, solar PV only & PV-wind hybrid system for 30 KW system of remote area. grid-tied PV-diesel generator for peak load requirement of 26 KW and grid-tied PV-wind hybrid energy system proposed rather than PV-wind standalone system due to lower cost of energy. Among the available RESs, solar PV source is the most available resource throughout country. The climatic conditions of Pakistan are ideal for solar energy-based power generation, like 8-9 hours of sunshine per day is available. This accounts for 5-7 $kWh/m^2/day$ average solar radiation having capacity of 2.9 million megawatts.

The remaining paper is organized as follows. Material and Method provides the basic introduction of the HOMER simulator and technical terminologies. Components of the hybrid grid-connected system discuss the basic components of the system, and it is followed by the Hybrid Power System Analysis. In the end Simulation and Optimization is followed by the Conclusion and References.

MATERIALS AND METHODS

Hybrid Optimization Model for Electric Renewables (HOMER), is a computer model used for designing of grid-connected and off grid-connected power system along with renewable & conventional energy resources which was developed in 1993 by National Renewable Energy Laboratory USA. Simulation, Optimization and sensitivity are the key features of HOMER.

- Simulation: HOMER simulates the result of design systems for each hour and determines all possible combinations with varying size over lifetime of project.
- Optimization: HOMER software evaluates all possible combinations of the system configuration and selects the best combination that fulfills the feasibility with the lowest cost.
- Sensitivity Analysis: Various optimizations are performed by entering several values for a specific input variable to decide the consequences of uncertainty.

HOMER considers the RESs as primary and conventional sources (grid, diesel generators) as secondary so firstly HOMER decides whether primary sources can fulfill the requirement of every hour of the year or not. If the requirement of energy is not fulfilled by primary sources, secondary sources are being used to fulfill the deficit of energy.

Net Present Cost: HOMER determines the NPC of each component in the system, and of the system as a whole. NPC of any system is the present value of all the costs of the system minus the present value of all the revenue of the system over its lifetime duration. Total NPC is the main economic output factor in HOMER by which all system configurations are ranked in optimization result and on the basis from which annualized COE and Levelized COE are calculated. NPC is calculated as

$$NPC = \frac{C_{Ann,\ Total}}{CRF}$$

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

N = Number of years
i = Annual interest rate = Nominal interest rate – inflation rate

Cost of Energy: Levelized COE defines as the net present value of the cost per unit of useful energy generated over the life cycle of the system.

$$COE = \frac{C\ ann, Total}{E\ served}$$

E_{served} = Energy served (KWh/year)

Emission of Greenhouse Gases: Emissions illustrate the total amount in (Kgs/yr) of each pollutant emitted by the power system annually. Emission of GHG, Unburned Hydrocarbons and Particular Matter are calculated by HOMER. Pollutants originate from fuel consumption in generators, boilers, and from consumption of grid power.

Components of Hybrid System: The hybrid power system can satisfy the requirement of the energy of a specific load whether load is commercial, industrial or residential with lower cost of energy production. The system model consists of diesel generators, PV system, Utility grid, converter, and load.

Utility Grid: The paper proposes a grid-connected hybrid power system located at Bhera city. The Bhera city is facing an average of 6-7 hours scheduled load shading in summer days and 4-5 hours in winter days. To compensate for this load shortage a hybrid power system is designed. The green area represents the availability of the grid, and the black pattern shows the grid supply not available for usage. Per unit cost of electricity for grid is considered as 0.15 $/KWh and sell back price to grid is 0.0400 $/kWh with100 KW of sale capacity with 3.61 $/KW/Month is considered. The demand rate that is being charged by the utility company in terms of Maximum Demand Indicator (MDI) during peak load (KW) of each month. Four hundred Pakistani rupees are charged per MDI.

Diesel Generation: *Perkin Diesel Generator:* Diesel generator (DG) of 260KW is selected to meet the requirement of peak load of the site in case of outage of grid and solar generation and its fuel consumption and efficiency curves are presented in Fig. 1. In existing power system, generator is being operational for approximately five hours per day due to shortage of power generation. Capital cost & replacement cost of 200$/KW is taken as per two largest Generator supplier groups of Pakistan (Power Zone company & Allied Engineering Services). Operation and maintenance cost is considered as 0.030 $ per hour. Minimum load ratio at generator considered as 25% of capacity & Diesel fuel price are fixed according to Pakistan market rate that is 0.81 $/liter.

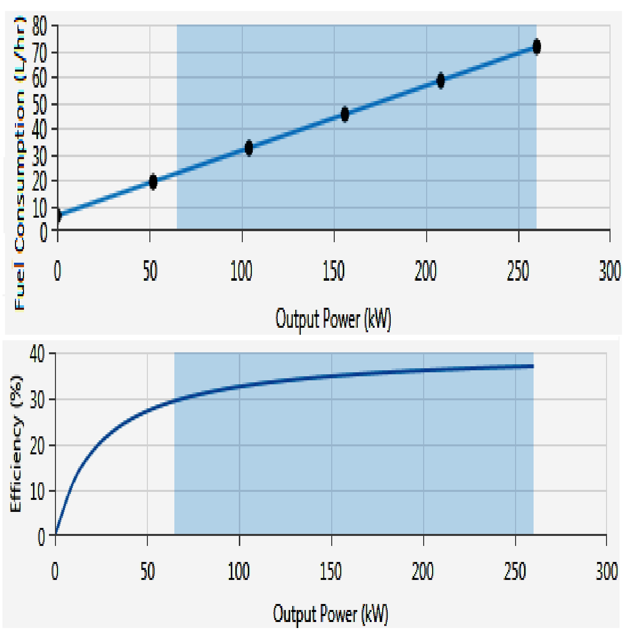

Figure-1. Fuel Consumption and Efficiency Curves

Caterpillar Diesel Generator: A generator of 90KW is chosen to operate at a lower load and its fuel consumption and efficiency curves are presented in Fig. 2. Fuel intercept curve of 90KW generator is 5.25 Liters per hour with capital cost & replacement cost of 200$/KW, and lifetime is 15000 hours. Average Power output is 70% of prime power output with the feature of withstands emergency usage of 10% exceeded their rating capacity for 1 hour. Maintenance cost is taken as 600 $ for 1000 hours for generator service.

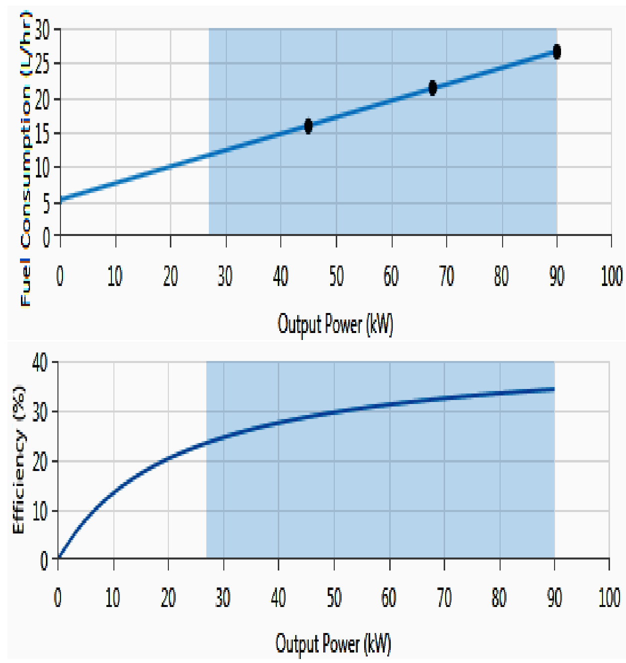

Figure-2. Efficiency and Fuel Consumption Curve

Solar PV Generation: After a survey of various products concentrating on cost, Trina Solar panels have been selected for the design of hybrid energy system as presented in Fig. 3. Trina Solar panels are considered as top-ranked due to its most reliable performance under all climatic conditions Capital and replacement costs are considered as 1500 $/kW in which cost of PV installation, labor cost, cost of structure, cost of wiring is included. Various ranges of PV panels are used to get better and optimized results by enabling HOMER Optimizer. Operation and Maintenance cost of 10$/yr. is taken for Trina solar with a total lifetime of 25 years. 80%, derating factor is considered to account such factors as wiring losses, shading, aging, and many others. Maximum Power Point Tracking (MPPT) system is not adopted because it is planned to install solar panels on the parking sheds of service areas.

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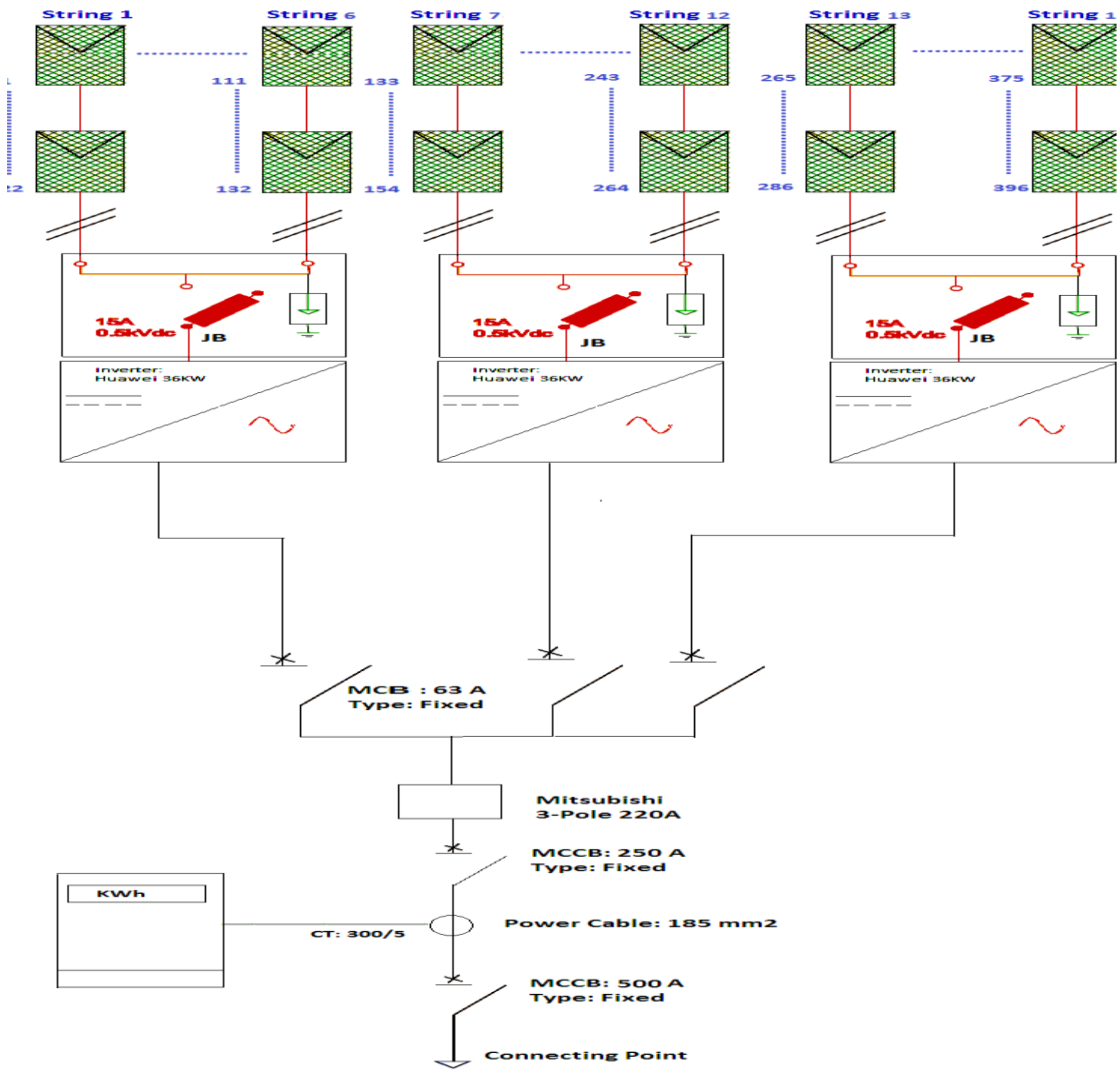

Figure-3. Design of PV System

Load Requirement: Motorway service area load profile is divided into following categories;

a) Restaurants load
b) Residential Load
c) Customer Service Providers

Connected load of restaurants (local & international food chain) are 192.6 KW and Customer Service Provider (CSP) centers & Residential area have 72.5KW & 92.9 KW respectively. The load details of the site are given in Table I.

Hybrid power system analysis: The objective of the simulation is to find the optimized system based on cost, considering the availability of the resources. Grid, Photovoltaic and diesel generators are the energy sources for the provision of energy to MSA. The COE of proposed system is lowest in all cases. The design of the proposed Hybrid Power System (HPS) and architecture of HPS and Utility grid are given in Fig. 4.

Table I. Load Details of Site at Bhera.

Month	Avg. Load (KW)	Max. Load (KW)	Daily Avg. Energy Consumption	Monthly Avg. Energy Consumption
January	76	100	1824	54720
February	77	101	1848	55440
March	83	128	1992	59760
April	88	130	2112	63360
May	117	179	2808	84240
Jun	124	218	2976	89280
July	152	230	3648	109440
August	130	230	3120	93600
September	122	181	2928	87840
October	102	179	2448	73440
November	101	155	2424	72720
December	81	103	1944	58320

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Peak Load	230	KW
Average Load	104	KW
Average Annual Energy Consumption per day	2506	KWh
Average Energy requirement in Summer (May- Aug)	3138	KWh
Avg. Energy consumption in Winter (Dec- Feb)	1872	KWh

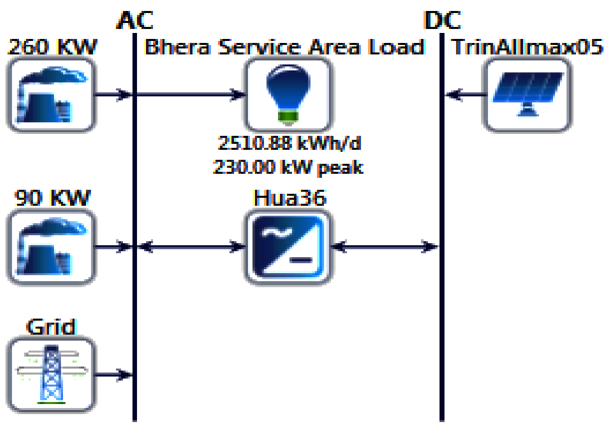

Figure-4: Design of proposed HPS

The simulator considers the PV system as a primary and Utility grid as secondary sources, respectively. A diesel generator is taken as backup when both sources are not available. Grid-tied hybrid system with combination of two diesel generators has least NPC and COE as compared to other four cases shown in Table II.

Two generators are operated at different hours of the day to provide maximum efficiency at a lower cost. HOMER provides sufficient information about each energy source in which total number of unit production, hours of operation, operational life and efficiency are measured. The detailed summary of energy from PV system, national grid and diesel generators are given in Table III, Table IV and Table V respectively.

PV penetration in the power system is about 40 % of the whole system. Levelized cost of per unit generation of solar is approximately 0.0728 $/KWh which is lowest in all energy sources. The reason behind the selection of 90 kW generator is that it consumes less amount of the fuel in an hour at full load as compared to 260 KW.

Table II. Cost Summary Hybrid Power System.

Cost Summary (Net Present Cost)	System ($)	Trina Solar ($)	Genset (260 kW) ($)	Genset (90 kW) ($)	Grid ($)	Huawei Inverter ($)
Capital	449,800.00	315,000.00	52,000.00	18,000.00	0.00	64,800.00
Replacement	45,346.38	0.00	17,853.44	0.00	0.00	27,492.94
O&M	1,248,501.55	27,147.78	93,203.09	3,914.86	1,124,235.81	0.00
Fuel	345,572.31	0.00	260,497.78	85,074.52	0.00	0.00
Salvage	14,027.65	0.00	8,253.11	600.10	0.00	5,174.45
Total	2,075,192.59	342,147.78	415,301.20	106,389.28	1,124,235.81	87,118.49

Table III. Solar Energy Detail of PV System.

PV Description	Trina Solar	Unit
Rated Capacity	210	kW
Mean Output	41.5	kW
Mean Output	996	kWh/d
Total Generation	363,700	kWh/yr.
PV penetration	39.7	%
Hours of Operation	4,384	hrs./yr.
Levelized Cost	0.0728	$/kWh

Table IV. Summary of Energy from the Grid.

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Energy Purchased (kWh)	Peak Load (kW)	Energy Charges ($)
Jan	32,678	5,423	27,255	97	$4,361
Feb	29,468	5,734	23,733	100	$3,797
Mar	35,995	4,461	31,534	128	$5,045
April	27,044	3,960	23,083	125	$3,693
May	43,645	1,728	41,918	179	$6,707
June	52,826	906	51,920	185	$8,307
July	70,813	262	70,551	225	$11,288
Aug.	58,371	1,200	57,171	229	$9,147
Sep.	60,224	2,677	57,546	181	$9,207
Oct.	47,445	3,943	43,502	179	$6,960
Nov.	44,378	4,329	40,050	131	$6,408
Dec.	39,037	5,782	33,255	103	$5,321
Annual	541,924	40,407	501,517	229	$80,243

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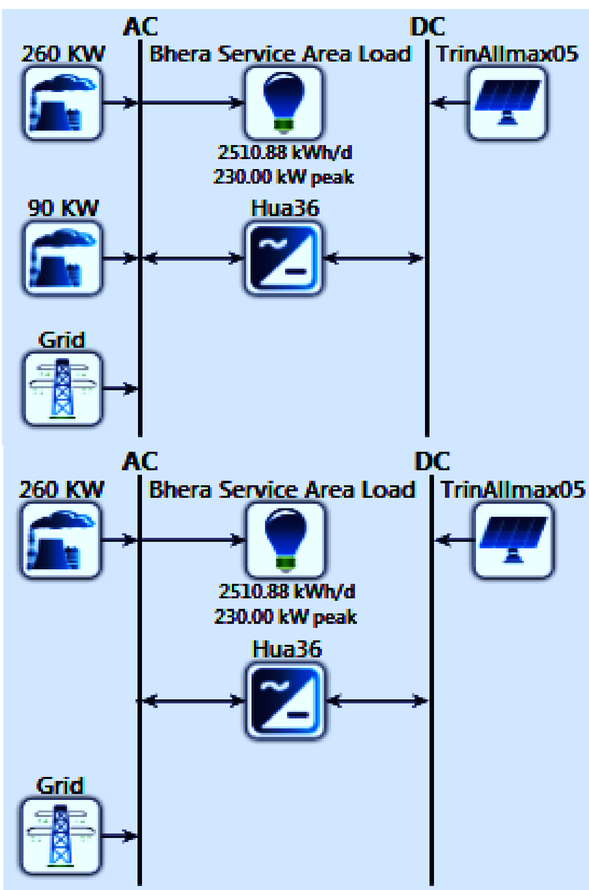
Table V. Generators Details of the DG System.

Description	Perkin Gen. (260KW)	Cat.Gen. (90KW)	Unit
Working Hours	802	504	hrs./yr
No. of Starts	604	380	starts/yr
Running/Working life	18.7	29.8	yr
Marginal generation cost	0.203	0.193	$/kWh
Electrical production	79,550	23,041	kWh/yr
Mean electrical output	99.2	45.7	kW
Minimum electrical output	65	27	kW
Maximum electrical output	225	81	kW
Fuel consumption	24,877	8,125	L/yr
Mean electrical efficiency	32.5	28.8	%

RESULTS AND DISCUSSION

Five different designs of t hybrid system are examined by integrating PV generator in an existing power system that are presented in Fig. 5.



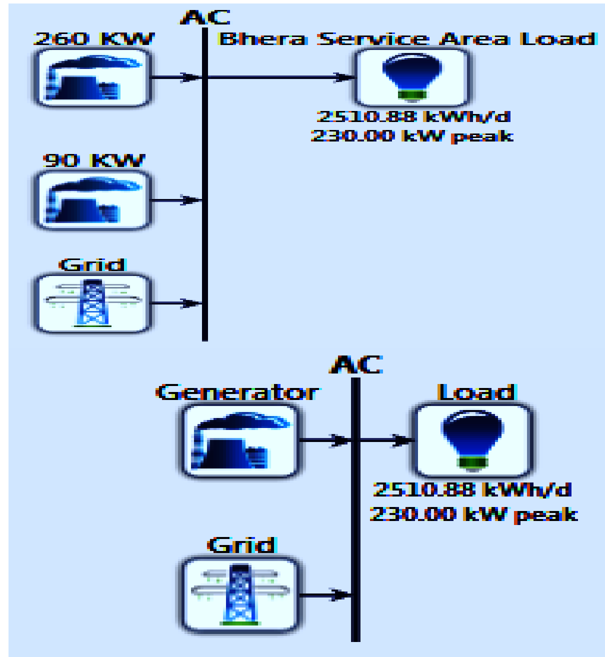


Figure-5: Comparison of various HPS Configurations

Data on renewable energy resources including monthly average Solar Horizontal Irradiance (GHI) and monthly average temperature are gathered from NASA Surface Meteorology and Solar Energy. Solar GHI is used to compute PV output by HOMER. GHI is the total solar radiation that incident on a horizontal surface. The following models of hybrid energy systems are studied in this research.

Case I: PV-Grid-Generator1+Generator2
Case II: PV-Grid-Generator1
Case III: Grid-Generator1+Generator2
Case IV: Grid-Generator1
Case V: Existing Power System

Financial Analysis: NPC and COE are the two main factors on which HOMER finds the pre-eminent solution through optimization and sensitivity analysis. The power system which has the lowest NPC and COE deliberates the best design to implement it at the site. The current (proposed) power system has a large capital cost but less operating cost in contrast to the Base (Existing) power system that has lower capital cost but high operating cost. This difference is due to non-availability of renewable energy and operation of large diesel generators. After 15 & 18.5 years, replacement cost of inverter & 260 KW generator added in system, the Net Annualized Cost (NAC) difference between Case I & Case IV is approximately $25138 which means that NAC of Case IV is 13.5% more than Case I so Case I is more cost-effective than all other hybrid energy systems as a comparison is presented in Fig. 6.

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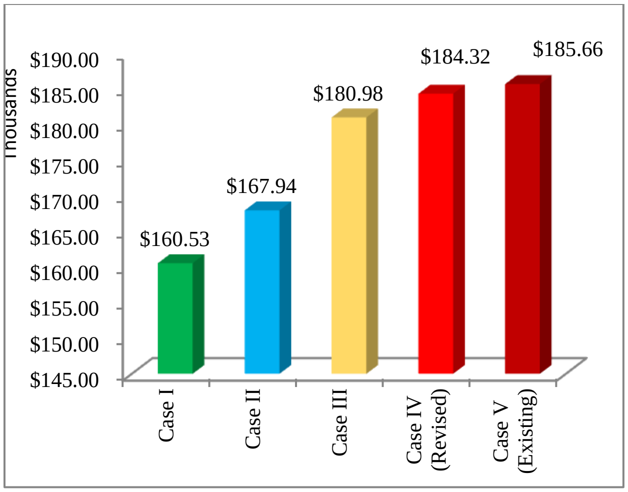

Figure-6. Comparison of the Annualized Cost of various HPS.

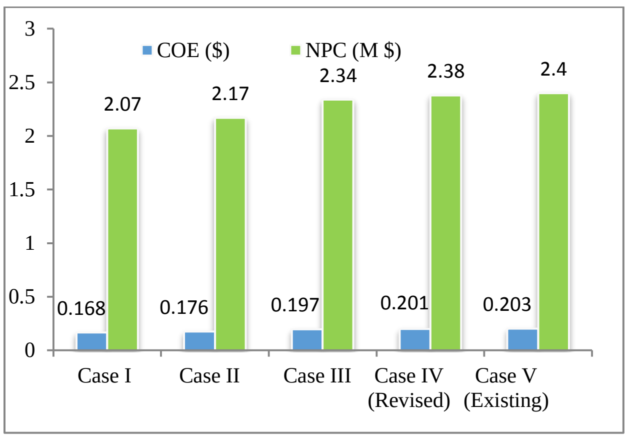

Figure-7 Comparison of NPC and COE of various HPS.

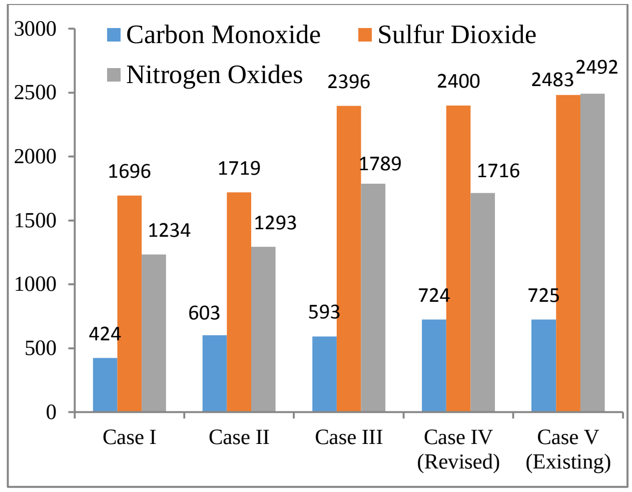

Figure-8 Comparisons of CO_2, CO Sulfur Dioxide.

COE and NPC for five different HPS configurations are compared in Fig. 7, and explained as follows:

- COE of Case I is approximately 16.4 %, which is less than the existing power system throughout the lifetime of the project so COE is lowest in Case I & highest in Case IV.
- NPC of Case I is approximately 12.9 % less than existing power system throughout the lifetime of the project so NPC is lowest in Case I & highest in Case IV.

Environmental Analysis: Greenhouse gases (GHG) play an important role in safe environment from pollution. GHG is the combination of gases that absorb & emit radiation. A comparison of GHG emission is given in Table VI.

Table VI. Comparison of GHG Emission.

Description	Case I	Case II	Case III	Case IV (Revised)	Case V (Exisiting)	Saving (kgs/Yr.)	Saving (%)	Saving (kg/Project Life time)
Co_2	429,090	438,225	602,220	603,630	638,927	209,837	33	5,245,924
CO	424	603	593	724	725	301	42	7525
Unburned HydroCarbons	18	26	26	32	34	19	46	393
Particulate Matter	4	4	5	4	9	5	57	123
SO_2	1696	1719	2396	2400	2483	787	32	19675
NO_x	1234	1293	1789	1716	2492	1258	50	31450

Unburned Hydrocarbons, Particulate Matter & Nitrogen Oxides of various Hybrid Power Systems are also comparerd in Fig. 8.

- During the comparison of the existing system with Case I, it is being witnessed that Proposed system saves 33% CO_2, 41% Carbon Monoxide, 47% Unburned Hydrocarbons and Saving of Sulfur Dioxide & Nitrogen Oxides are 32 % & 47% respectively as compared to existing power system throughout the lifetime of project.

Technical Analysis: Operational life, total fuel consumption and mean electrical efficiency of each case are computed. Average fuel consumption of Case I & Case IV are 3.77 L/hr and 6.49 L/hr respectively So fuel consumption of Case I is 72% less as compared to the existing power system and 32% as compared to Case IV (Revised) due to penetration of renewable energy that is shared in Table VII.

Table VII. Comparisons of Operational life, Total Fuel Consumption and Mean Electrical Effeciency.

System	Case I	Case II	Case III	Case IV (Revis.)	Case V (Exist.)
Grid (KWh/Yr.)	541924	541924	773351	773351	773351
Grid (%) Contribution	53.75	53.16	84.38	84.40	83.83
Generator (KWh/Yr.)	102591	113882	143118	142995	149121
Generator (%) Contribution	10.18	11.17	15.62	15.60	16.17
Solar (KWh/Yr.)	363700	363700	0	0	0
Solar (%) Contribution	36.07	35.67	0	0	0
Total Prod. (KWh/Yr.)	1008215	1019506	916469	916346	922472

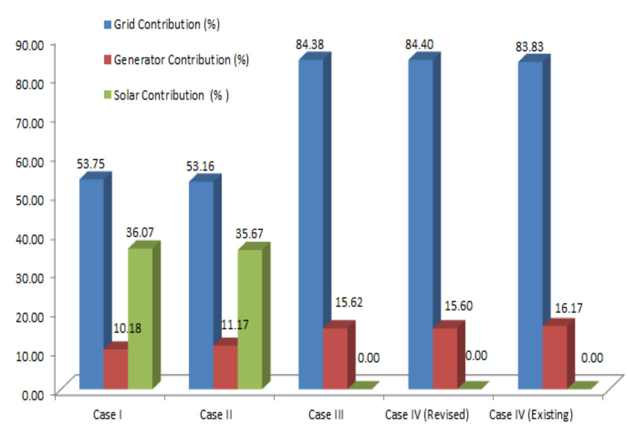

Figure-9: Percentage Contribution of various energy sources.

Contribution of the energy sources in HPS for analyzed cases is given in Fig. 9. Contribution of the generator is least in case I as compared to all other cases which are beneficial for the proposed system because the lower contribution of the generator decreases the cost of energy and emission of GHG. The contribution of solar PV is largest in Case I as compared to all other cases to reduce the cost of energy.

Conclusion: Five different configurations of power systems are evaluated and compared in this research work for delivering power to a specific peak load of 230KW through HOMER. Keeping in mind the lower emission of GHG, reduction in fuel consumption and lower COE, grid-tied PV-diesel generators hybrid system (Case I) is established to be the most optimal solution. COE of proposed system is considered as Rs.18.5/Kwh which is lowest in all evaluated hybrid systems and approximately equal to present COE for grid which is Rs.17.7/Kwh for specific proposed site but due to unreliability of grid, PV and diesel generator are connected with existing system. The initial capital cost of proposed hybrid system is high but it should not be taken as decisive factor in Build-Operate-Transfer project considering 25 year lifetime. To reduce the emission of GHG, especially CO2, PV is added to the grid-connected system, so as a result 33% saving in CO2,42% in CO,32% in SO2 and 47% in Nitrogen oxides are achieved through proposed system (Case I) as compared to existing power system. Fabulous improvement in NPC, COE and GHG emission is witnessed in this research.

REFERENCES

Abbas, G., J. Gu, U. Farooq, M.U. Asad and M. El-Hawary (2017). Solution of an economic dispatch problem through particle swarm optimization: a detailed survey-part I. *IEEE Access*, *5*, 15105-15141.

Abbas, G., J. Gu, U. Farooq, M.U. Asad and M. El-Hawary (2017). Solution of an economic dispatch problem through particle swarm optimization: A detailed survey–Part II. *IEEE Access*, *5*, 24426-24445.

Abujubbeh, M., V. T. Marazanye, Z. Qadir, M. Fahrioglu and C. Batunlu (2019). Techno-Economic Feasibility Analysis of Grid-Tied PV-Wind Hybrid System to Meet a Typical Household Demand: Case Study. Amman, Jordan, *2019 1st Global Power, Energy and Communication Conference (GPECOM)*, Nevsehir, Turkey, 2019, pp. 418-423.

Bataineh, A., A. Alqudah and A. Athamneh (2014). Optimal Design of Hybrid Power Generation System to Ensure Reliable Power Supply to the Health Center at Umm Jamal Mafraq, Jordan. Energy and Environment Research, 4(3), 9-20.

Garni, H.A. and A. Awasthi (2017). Techno-economic feasibility analysis of a solar PV grid-connected system with different tracking using HOMER software. 2017 IEEE International Conference on Smart Energy Grid Engineering (SEGE), Oshawa, ON , pp. 217-222

Ghose, S., A. El Shahat and R.J. Haddad (2017). Wind-solar hybrid power system cost analysis using HOMER for Statesboro, Georgia. SoutheastCon 2017, Charlotte, NC, pp. 1-3.

Habib, H.R. and T. Mahmood (2017). Optimal planning and design of hybrid energy system for UET Taxila. 2017 International Conference on Electrical Engineering (ICEE), LahorE, pp. 1-9

Iqbal, A., I.F. Muhammad, M. Faraz, M.S. Tariq and H.U. Banna (2015). Economic analysis of a small hybrid power system. 2015 Power Generation System and Renewable Energy Technologies (PGSRET), Islamabad, pp. 1-5

Kundankar, R.R. and P.K. Katti (2018). Hybrid Energy System for Remote and Rural Villages. *2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC)*, Greater Noida, India, 2018, pp. 619-622

Kusakana, K. (2017). Techno-economic analysis of multiple paralleled diesel generators for micro isolated applications. International Conference on the Domestic Use of Energy (DUE), Cape Town , pp. 2-7.

Kushida, T. and R. Abe (2016). Optimal design of a grid connected PV-diesel hybrid system. 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), Florence, pp. 1-4.

Mahmood, M.S. and M.S. Mahmood (2017). Cost effective optimal solution for hybrid power system among diverse sources of renewable energy. TENCON 2017 - 2017 IEEE Region 10 Conference, Penang, , pp. 1231-1234.

Shaikh, P., S. Faheemullah and M. Mirani (2013). Solar energy: Topographical asset for Pakistan. Applied Solar Energy.Review, 14, 354–363.

Shair, J. and M.K. Abbas (2016). Economic viability of grid tied solar PV energy system in Muzaffargarh, Pakistan. 2016 19th International Multi-Topic Conference (INMIC), Islamabad, pp.1-6

Wicaksana, H., M.M. Muslim, S.F. Hutapea, A. Purwadi and Y. Haroen (2016). Design, implementation and techno-economic analysis of hybrid PV-Diesel for Off-grid system in Sebira Island. 2016 3rd Conference on Power Engineering and Renewable Energy (ICPERE), Yogyakarta, pp. 39-44.