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# Design And Performance Analysis Of Wind-Pv-Diesel Generator Hybrid Power System For A Hilly Area Rangamati Of Bangladesh

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**ABSTRACT :** This research proposed a hybrid power generation system suitable for a hilly area application. The methododology of this research was the collection of the basic data of solar radiation, wind speed and other required input data. Optimization simulation model was developed using the electric renewable energy software hybrid optimization model of renewable energy (HOMER). The model has designed to provide an optimal system configuration based on hour-by-hour data for energy availability and demands. Various renewable/alternative energy sources, energy storage and their applicability in terms of cost and performance are discussed. The Sensitivity analysis was carried out using Homer software. According to simulation results, it has been found that renewable energy sources will replace the conventional energy sources and would be a feasible solution for distribution of electric power for standalone applications at remote and distant hilly locations.

**Keywords :** Renewable energy, Hybrid power system, Cost of energy, Payback period, HOMER.

## 1 INTRODUCTION

Bangladesh is an over densely populated country in the world, and hence its energy demand is growing with time. It has been facing difficulties in supplying energy to retain its large population & economic growth. The current demand for energy exceeds the available resources. Now, it is the time to think alternative energy sources. It is needed to interconnect renewable/alternative energy sources. Renewable energy sources offer a viable alternative to the endowment of power in rural areas [1], [2], [3], [4], [5], [6]. Renewable Energy is clean, green, pollution less, endless energy source [7]. Solar radiation, wind, hydro, biomass and tide are common sources of renewable energies [8]. As all of the renewable resources are natural and weather dependent. Renewable energy sources have unpredictable random behaviors [9]. However, some of them, like solar radiation and wind speed, have complementary profiles [10]. A consistent utilization of the complementarities of these two sources of energy with battery storage and diesel generator as backup seems necessary to maintain a stable level of electricity production in favorable sites [11]. Improvements in wind turbine and PV generation technologies have brought opportunities for utilizing wind and solar resources for electric power generation [12]. It has been reported that in weak grids, the wind or PV hybrid system is superior than only wind or PV generation system since it suppresses rapid change in the output power of the single source such as the wind turbine system [13]. Grid interface of the hybrid system with battery storage improves system reliability [14], [15]. However, these systems must address the practical aspects of what seems feasible from business and economic perspectives. Demonstrations of system-level pilot projects have provided a critical portion of the information for the application and the formation of a much wider market. The inability to guarantee reliable, uninterrupted output at a cost that can be comparable to conventional power generation has been the drawback of wind or photovoltaic systems. Therefore, a number of off-grid hybrid systems, which have received more and more attention, were installed and tested in the past decades [16]. The common purpose is to make best use of renewable resources and to reduce cost and finally to convert it into the most reliable and popular power resource. Many literature references have discussed how to determine the optimum combination of a hybrid energy system. The results clearly show that, renewable energy based off-grid hybrid generation systems can compete with power from the grid in remote locations [17], [18]. The objective of this work is to analyze the cost benefit, payback period of a solar-wind-diesel generator hybrid power system for a hilly area Rangamati, Bangladesh when compared to cost per kilowatt of utility power supply. In these research paper, we Analysis the reliability of the overall hybrid system,use renewable sources for energy production, compare cost of electricity and Finally Sensitivity analysis using simulating software HOMER. Analysis reveals that the hybrid system with Wind-PV-diesel generator gives superior performance in terms of cost and sensitivity.

## 2 PROPOSED HYBRID POWER SYSTEM

### 2.1 Selected Area

Bangladesh is situated between 20°34' and 26°38' N latitudes and 88°01' and 92°41' E longitudes with nearly 16 crore people living on 147570 square kilometer land area. There are many hilly areas in Bangladesh. One of them is Rangamati, geographically situated in Chittagong Division, Bangladesh, Asia and its geographical coordinate is 22.6333° N, 92.2000° E, is a suitable place for planning stand-alone hybrid power system because this is not possible to launch grid connected system in this hilly area. For confirming steady and continuous electricity generations, a hybrid power system including more than one renewable energy elements is introduced. In this paper, ecological and commercial analyses are used to discuss the sustainability of a hybrid power system. An research is made on small-scale operations of 92.8 kWh per day hybrid power system as a standalone power generation system consisting of solar (PV), wind energy and diesel generator .

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### 2.2 System Components

A standalone PV,Wind,Diesel generator hybrid power system has been proposed consisting of :

- Generic 3kW Wind Energy Generator
- Photovoltaic Array
- Diesel Generator
- Battery
- Converter
- Constraints

***Fig.1*** *shows the block diagram of proposed hybrid system consisting of PV, Wind and diesel generator.*

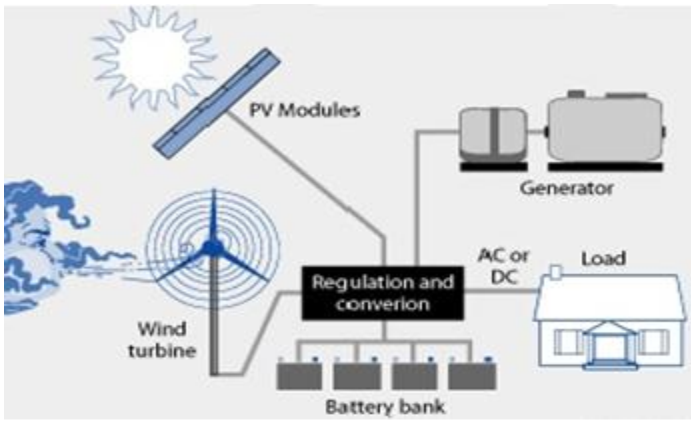


***Fig.1:*** *The proposed hybrid system*

### 2.3 Electric Load

A community of 1000 people, 100 households, one market, one school and one mosque has been considered for estimation of electric load. Two energy efficient lamps (CFL, 15W each) for each solvent family are considered. Table-1 and Table-2 show that

***Table-1:*** *Appliance, Capacity and Maximum used time*

| **Appliance** | **Capacity(W)** | **Maximum use (hour/day)** |
|---|---|---|
| Florescence light | 15 | 7 |
| Color TV | 70 | 4 |
| Fan | 100 | 6 |

***Table-2:*** *Appliance, Capacity and Maximum used time*

| **Family criteria** | **Numbers Of Family** | **Quantity/per family** | | | **Florescence light (kWH/day)** | **Fan (kWH/day)** | **Color TV (kWH/day)** | **Total (kWH/day)** |
|---|---|---|---|---|---|---|---|---|
| | | **Light** | **Fan** | **TV** | | | | |
| **Solvent** | 25 | 2 | 2 | 1 | 5.500 | 19.000 | 10 | 92.725 ≈93 kWH/day |
| **Poor** | 75 | 1 | 1 | 0 | 7.875 | 32.000 | 0 | |
| **School** | 2 | 3 | 3 | 0 | 0.630 | 3.600 | 0 | |
| **Mosque** | 1 | 1 | 1 | 0 | 0.020 | 1.000 | 0 | |
| **Market** | 1 | 4 | 2 | 2 | 0.600 | 2.500 | 10 | |
| **Total** | | | | | 14.625 | 57.1000 | 20 | |

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### 2.4 System Architechture

The ratings of the equipments were considered optimistically in the initial stage. As a next step, the equipments were considered on optimal basis for providing the economic feasibility of the proposed system. The list of the equipments is tabulated in Table-3.

***Table-3:*** *The list of the equipments*

| | |
|---|---|
| PV Array | 5 kW |
| Wind turbine | 1 Generic 3kW |
| Wind turbine | 5 Generic 3kW |
| Generator 1 | 5 kW |
| Battery | 40 Surrette 4KS25P |
| Inverter | 7 kW |
| Rectifier | 7 kW |
| Dispatch strategy | Cycle Charging |

To design a hybrid power system, information, such as the load profile, for a particular remote location is to be provided that should be met by the proposed hybrid system. Also, the initial cost for each component (diesel, renewable energy generators, battery, converter), cost of diesel fuel, annual interest rate, project lifetime, etc. are to be included.

***Table-4:*** *Components and their cost*

| **Component** | **Size** | **Capital Cost (BDT)** | **Replace-ment Cost** | **O&M Cost ($)** | **Life-time** |
|---|---|---|---|---|---|
| PV Panels | 5.00 kW | 960000 | 0 | 0.00 | 20years |
| S4KS25P Battery | 4V,1900A,7.46kWh | 800000 | 800000 | 500/year | 4years (10569 kWh of throughput per battery) |
| Generic Wind Turbine | 3 kW DC | 40000/3kW | 320000/3kW | 40000/year | 20 years |

The size of the components under consideration, the acquisition cost, replacement cost, operation and maintenance cost and the expected lifetime as input into the HOMER software are depicted in Table-4. The remote location we selected a hilly area of Bangladesh – Rangamati (22.6333° N, 92.2000° E.After selecting this remote location we have collected PV radiation data and wind speed data of that location. Then, we performed the simulation to obtain the best hybrid power system configuration utilizing HOMER software from NREL. HOMER simulations are performed by analyzing energy balance calculations and show all the possible configurations arranged by net present cost which can be useful for comparison of system design. HOMER's optimization and sensitivity analysis made this task possible. Also it finds all potential system configurations related to it.

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## 3 HOMER SIMULATION

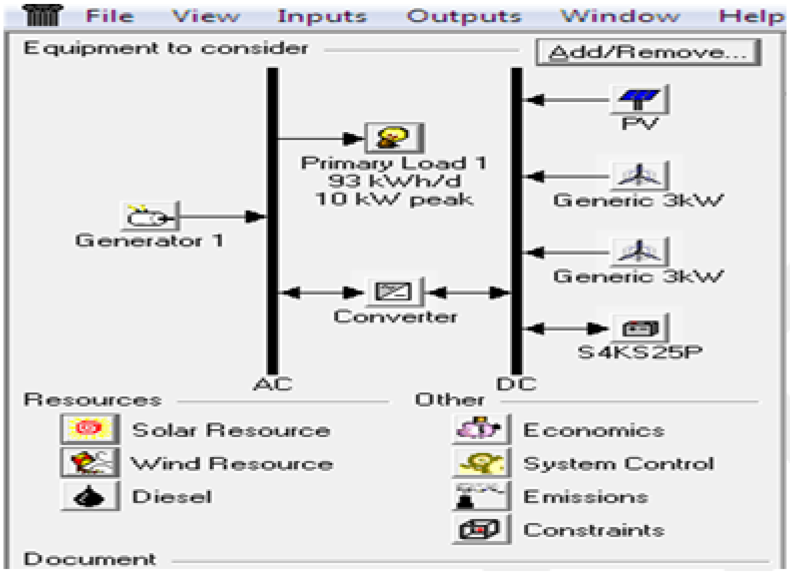


***Fig.2:*** *Proposed Hybrid Power System in HOMER*

### 3.1 PRIMARY LOAD PROFILE

An average demand of a general load centre with approximately 93 kWh/day is considered. In this analysis, the load is modeled with a few peak demands of almost 10 kW and a load factor of 0.384, i.e., the average power divided by the peak power over a span of 24 hours which is shown in Fig.3 & Table-5.

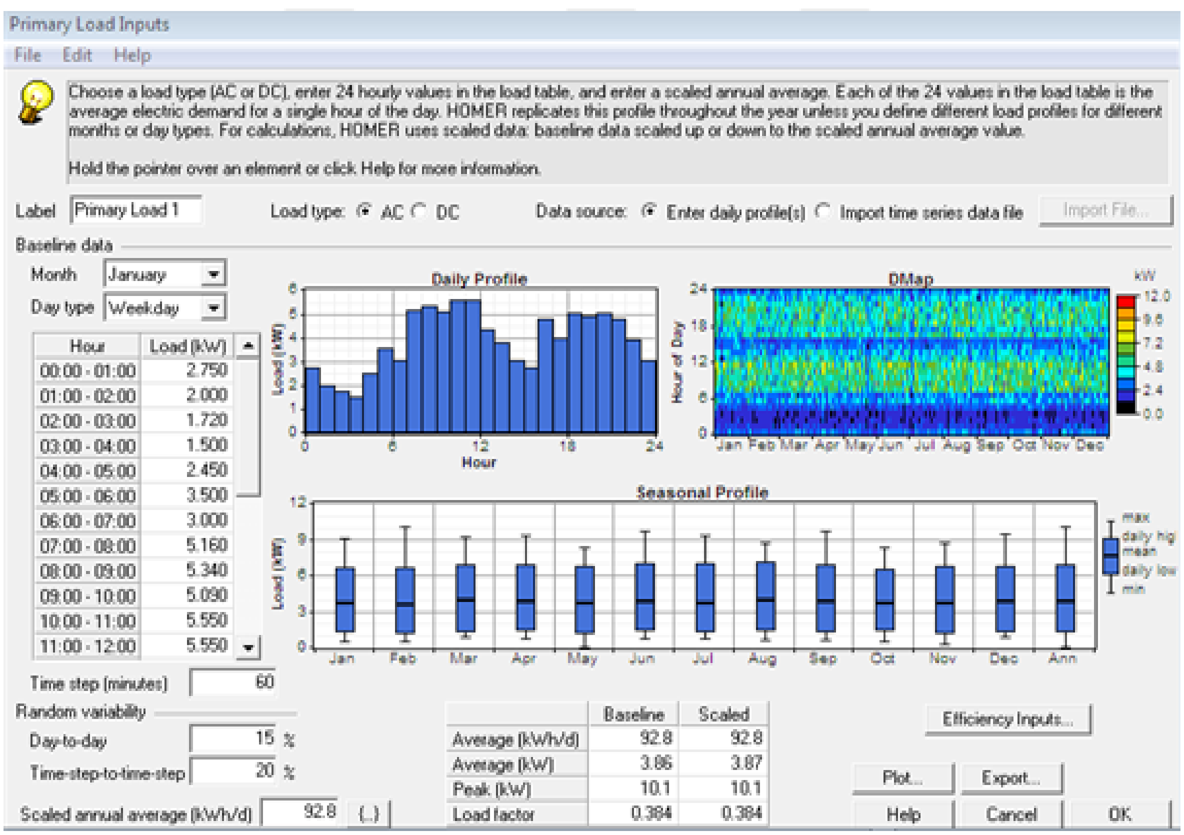


***Fig.3:*** *Load Profile of proposed hybrid system*

***Table-5:*** *Yearly load conjumption with fraction*

| **Load** | **Consumption** (kWh/yr) | **Fraction** |
|---|---|---|
| AC primary load | 33,867 | 100% |
| Total | 33,867 | 100% |

## 3.2 Solar Resource Profile

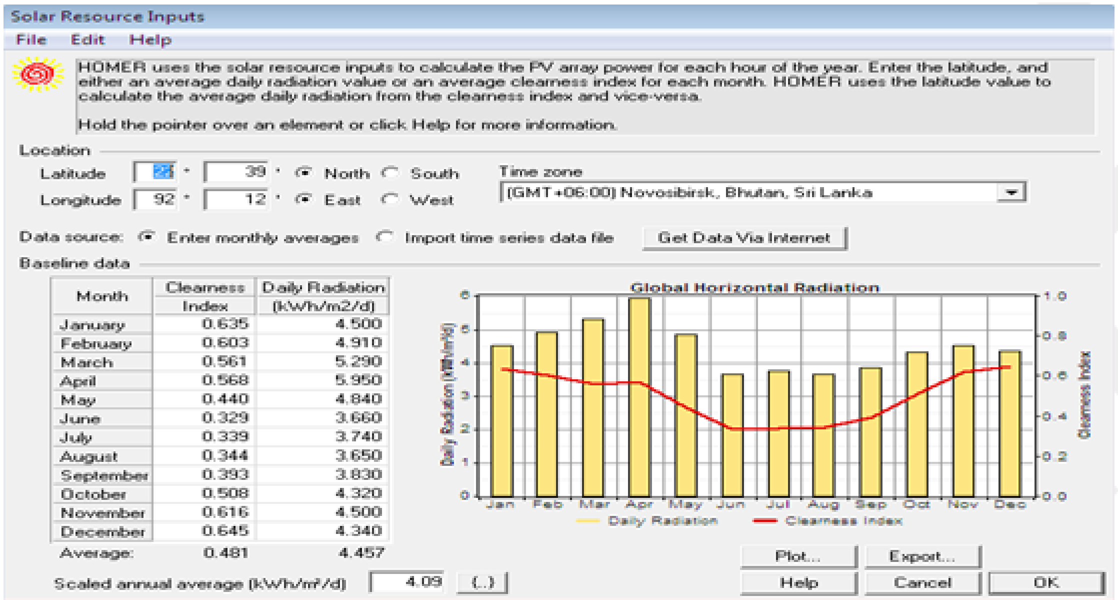


***Fig.4:*** *Solar resources Profile of Rngamati, Bangladesh*

## 3. 3 Wind speed profile

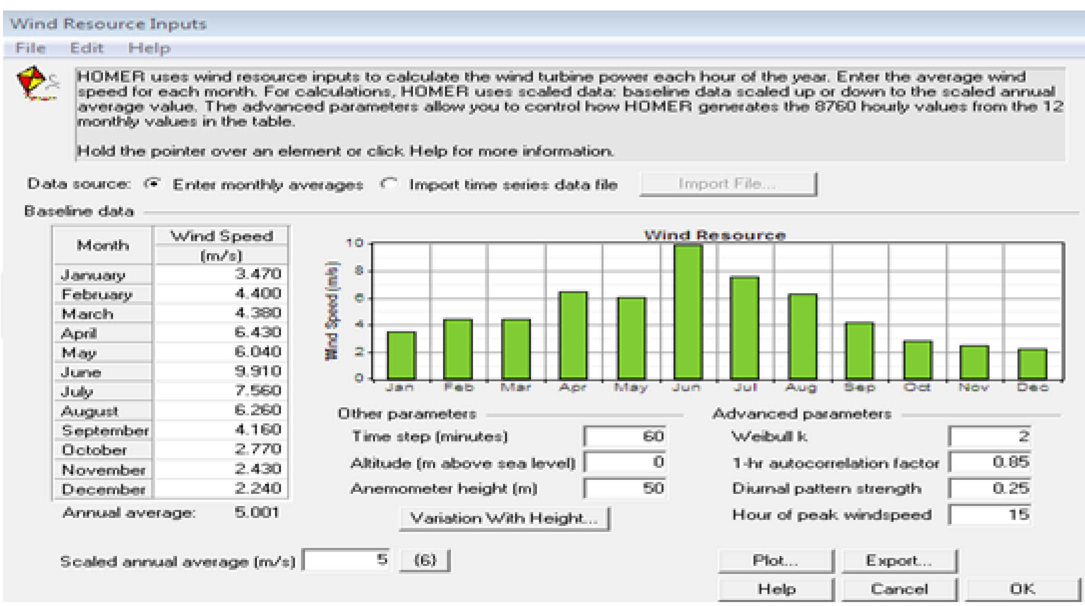


***Fig.5:*** *Wind speed Profile of Rngamati, Bangladesh*

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Fig.4 and Fig.5 show the solar radiation profile and wind speed profile of our desired location Rangamati of Bangladesh respectively.

***Table-5:*** *Specification of diesel generator and battery*

| **Diesel Generator Profile** | | **Battery Profile** | |
|---|---|---|---|
| Sizes to consider | 5 kW | Battery | Surrette 4KS25P |
| Lifetime | 15,000 hrs | Quantities to consider | 32, 34, 35, 36, 40, 42 |
| Min. load ratio | 30% | Voltage | 4 V |
| Heat recovery ratio | 0% | Nominal capacity | 1,900 Ah |
| Fuel used | Diesel | Lifetime throughput | 10,569 kWh |
| Fuel curve intercept | 0.08 L/hr/kW | Min battery life | 4 yr |
| Fuel curve slope | 0.25 L/hr/kW | | |
| Lower heating value | 43.2 MJ/kg | | |
| Density | 820 kg/m3 | | |
| Carbon content | 88.0% | | |
| Sulfur content | 0.330% | | |

***Table-6:*** *Specification of converter and constraints*

| **Converter** | | **Constraints** | |
|---|---|---|---|
| Sizes to consider | 0, 7, 12 kW | Maximum annual capacity shortage | 0% |
| Lifetime | 20 yr | Minimum renewable fraction | 0% |
| Inverter efficiency | 90% | Operating reserve as percentage of hourly load | 10% |
| Inverter can parallel with AC generator | Yes | Operating reserve as percentage of peak load | 0% |
| Rectifier relative capacity | 100% | Operating reserve as percentage of solar power output | 25% |
| Rectifier efficiency | 85% | Operating reserve as percentage of wind power output | 50% |

Specification of diesel generator , battery, converter, constraint and at sensity case are shown in Table-5,Table-6 and Table-7 respectively.Fig. 6 illustrates the efficiency curve of the system.

***Table-7:*** *Specification at sensityvity case*

| | |
|---|---|
| Wind Data Scaled Average | 5 m/s |
| Diesel Price | 0.8$/L |
| Surrette 4KS25P Capital Cost Multiplier | 1 |
| Simulation Time Step | 40 min |

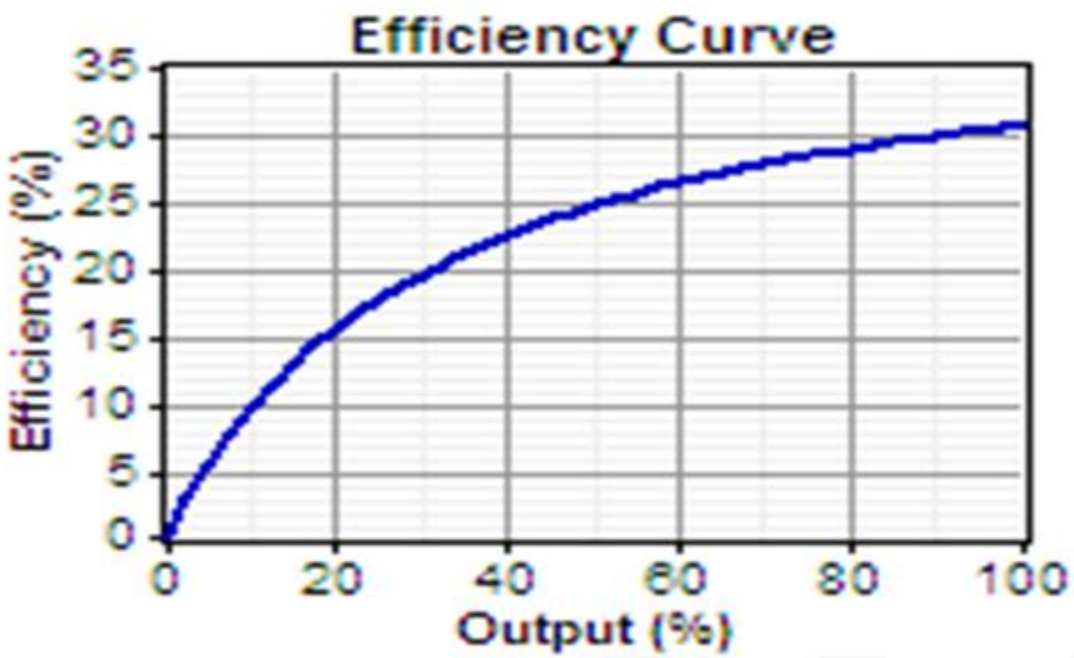



***Fig.6:*** *Efficiency curve of the proposed system*

## 4 Results and Discussion

### 4.1 Optimization result

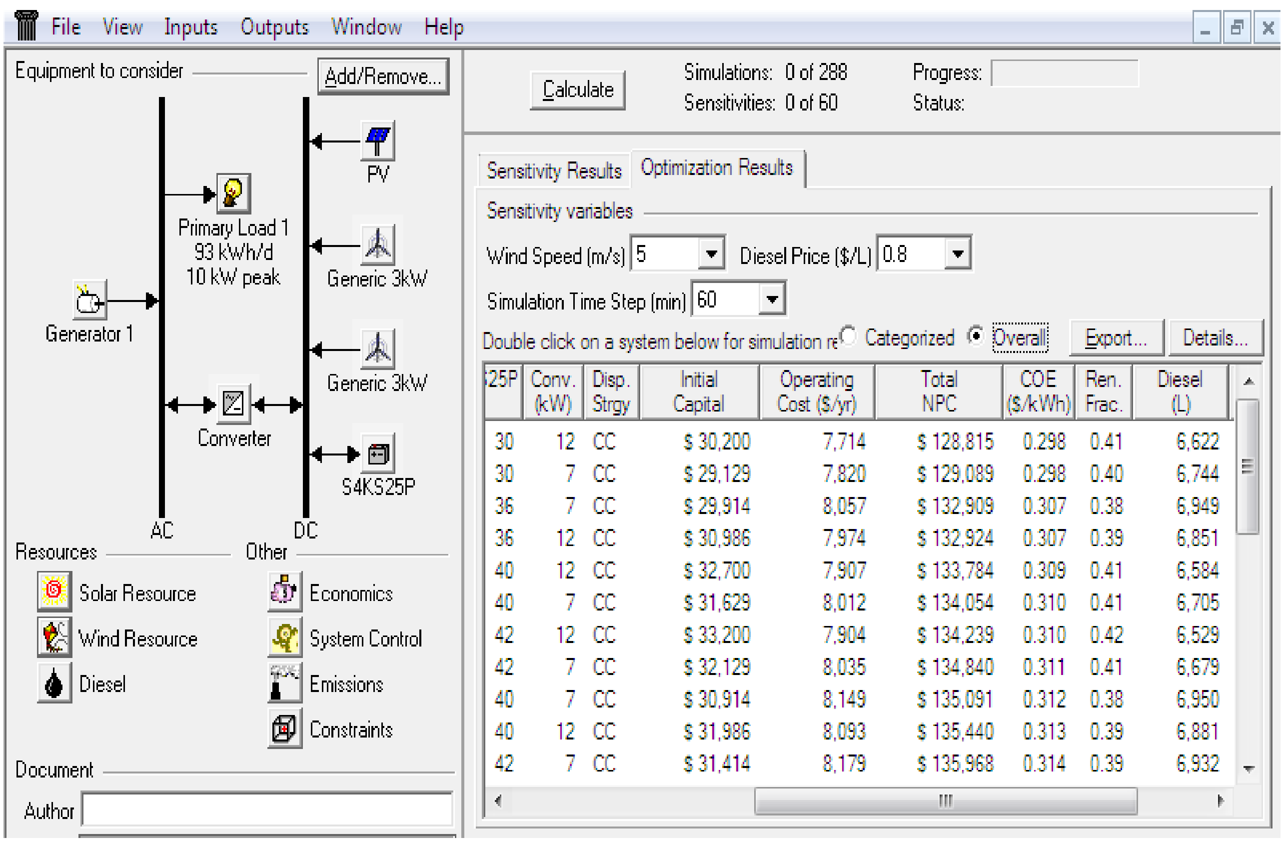
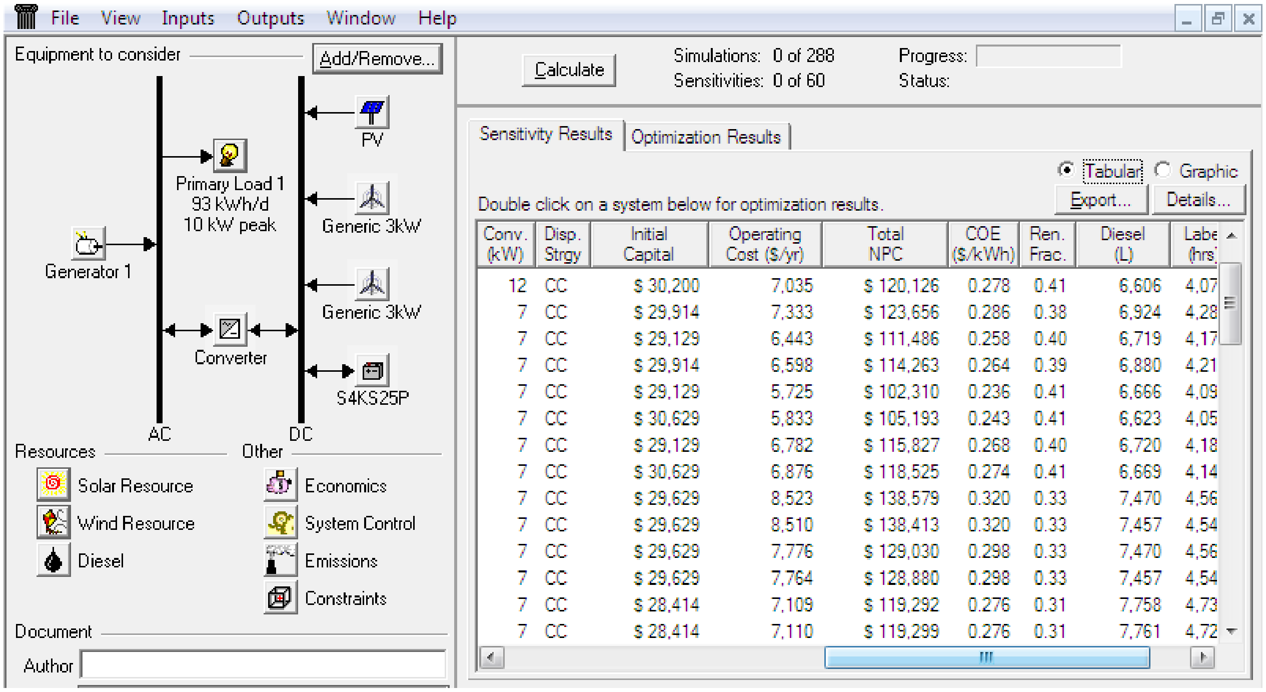


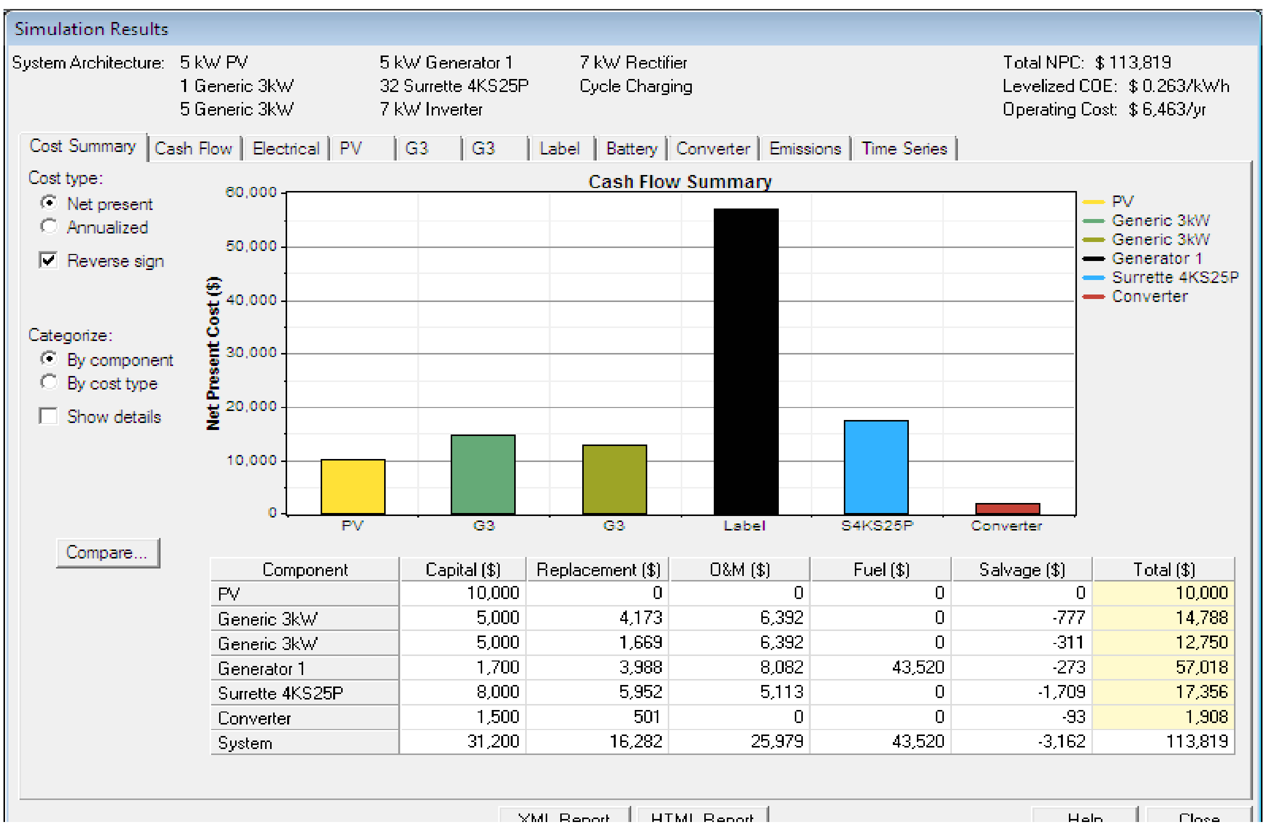

***Fig.7:*** *Optimization result of HOMER simulation*

### 4.2 Sensitivity result




| Conv. (kW) | Disp. Strgy | Initial Capital | Operating Cost ($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Diesel (L) | Labe (hrs) |
|---|---|---|---|---|---|---|---|---|
| 12 | CC | $ 30,200 | 7,035 | $ 120,126 | 0.278 | 0.41 | 6,606 | 4,07 |
| 7 | CC | $ 29,914 | 7,333 | $ 123,656 | 0.286 | 0.38 | 6,924 | 4,28 |
| 7 | CC | $ 29,129 | 6,443 | $ 111,486 | 0.258 | 0.40 | 6,719 | 4,17 |
| 7 | CC | $ 29,914 | 6,598 | $ 114,263 | 0.264 | 0.39 | 6,880 | 4,21 |
| 7 | CC | $ 29,129 | 5,725 | $ 102,310 | 0.236 | 0.41 | 6,666 | 4,09 |
| 7 | CC | $ 30,629 | 5,833 | $ 105,193 | 0.243 | 0.41 | 6,623 | 4,05 |
| 7 | CC | $ 29,129 | 6,782 | $ 115,827 | 0.268 | 0.40 | 6,720 | 4,18 |
| 7 | CC | $ 30,629 | 6,876 | $ 118,525 | 0.274 | 0.41 | 6,669 | 4,14 |
| 7 | CC | $ 29,629 | 8,523 | $ 138,579 | 0.320 | 0.33 | 7,470 | 4,56 |
| 7 | CC | $ 29,629 | 8,510 | $ 138,413 | 0.320 | 0.33 | 7,457 | 4,54 |
| 7 | CC | $ 29,629 | 7,776 | $ 129,030 | 0.298 | 0.33 | 7,470 | 4,56 |
| 7 | CC | $ 29,629 | 7,764 | $ 128,880 | 0.298 | 0.33 | 7,457 | 4,54 |
| 7 | CC | $ 28,414 | 7,109 | $ 119,292 | 0.276 | 0.31 | 7,758 | 4,73 |
| 7 | CC | $ 28,414 | 7,110 | $ 119,299 | 0.276 | 0.31 | 7,761 | 4,72 |

***Fig.8:*** *sensitivity result of HOMER simulation*




| Component | Capital ($) | Replacement ($) | O&M ($) | Fuel ($) | Salvage ($) | Total ($) |
|---|---|---|---|---|---|---|
| PV | 10,000 | 0 | 0 | 0 | 0 | 10,000 |
| Generic 3kW | 5,000 | 4,173 | 6,392 | 0 | -777 | 14,788 |
| Generic 3kW | 5,000 | 1,669 | 6,392 | 0 | -311 | 12,750 |
| Generator 1 | 1,700 | 3,988 | 8,082 | 43,520 | -273 | 57,018 |
| Surrette 4KS25P | 8,000 | 5,952 | 5,113 | 0 | -1,709 | 17,356 |
| Converter | 1,500 | 501 | 0 | 0 | -93 | 1,908 |
| System | 31,200 | 16,282 | 25,979 | 43,520 | -3,162 | 113,819 |

***Fig.9:*** *Cash flow summary result of HOMER simulation*

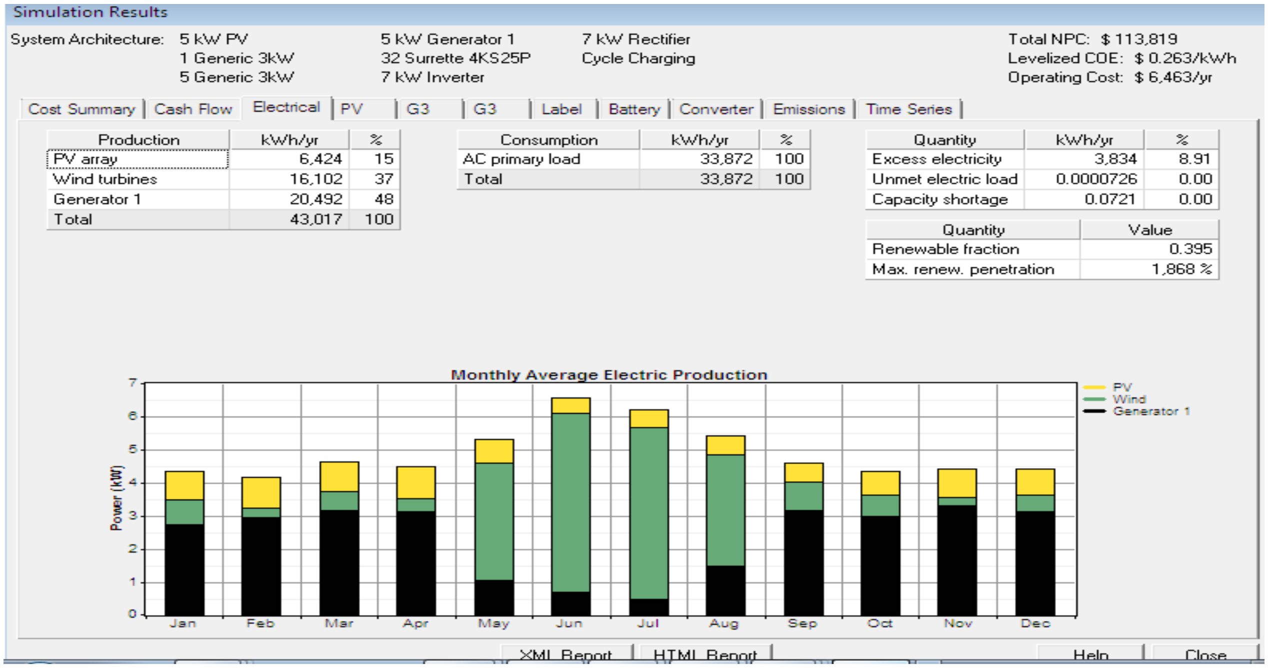



***Fig.10:*** *Monthly average electric production*

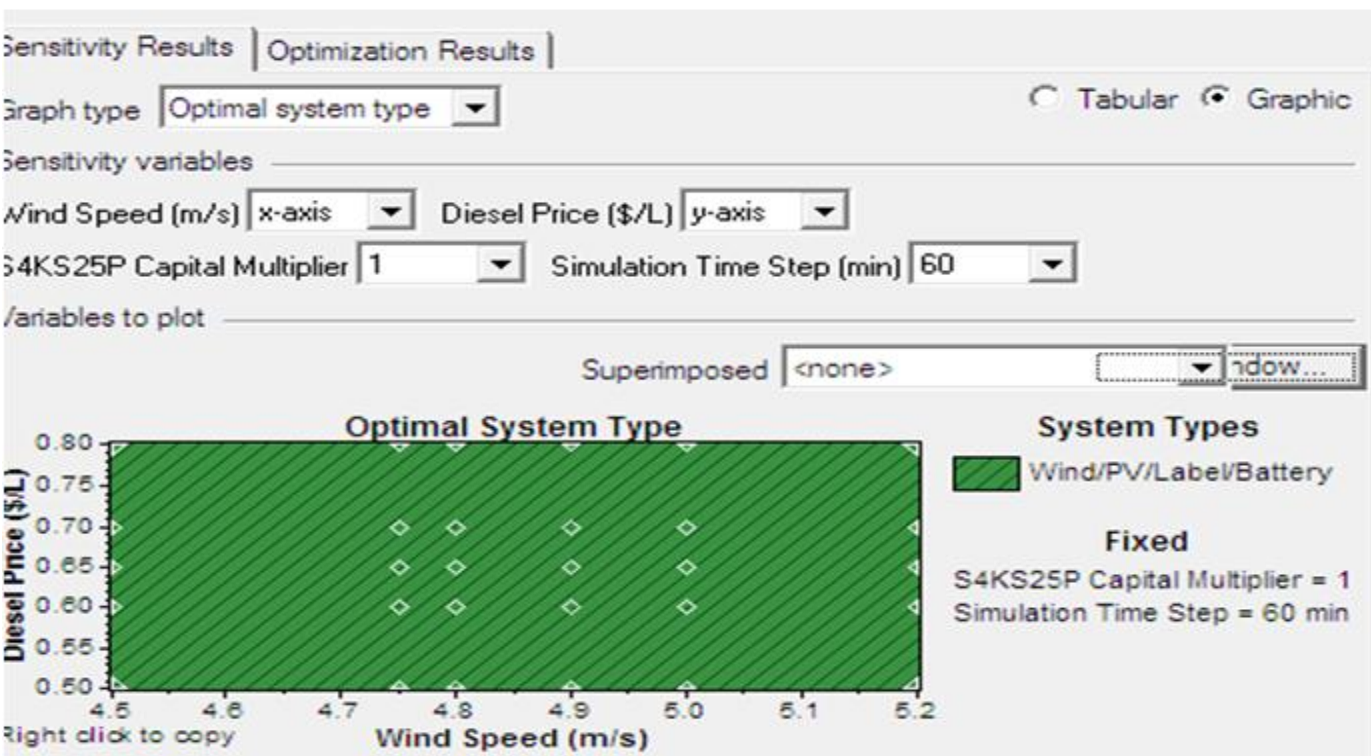



***Fig.11:*** *Optimal systems in terms of Diesel price and wind speed*

The annual electric energy production , annual electric energy consumption, the production power by individual renewable source are shown in Fig.9 and Fig.10 . The levelized COE is signified in Fig.11. Using HOMER software the system performance analysis has been evaluated. The optimized result is analyzed for solar radiation 4.09WH/m2/d, wind speed 5m/s diesel price TK.64BDT.The results obtained from the current research clearly reveals that, the hybrid power system consisting of two Generic 3 kW wind turbine, one 5 kW PV array, 5 kW Diesel generator, 32 batteries and 7 bi-directional converter to link AC and DC bus, requires minimal production cost. Initial cost of such a system would be 9105528 BDT and it will produce electricity 43017 kWH/yr at a cost of 21.00 BDT/kWh (1 USD = 80 BDT). So, the total amount of annual income is 903357BDT (43017*21) and payback period is aprox. 10 years. Such a system would result in a renewable energy fraction of 0.395.

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## 5 CONCLUSION

From our current research the HOMER simulation result is promising. Here, the excess electricity is 3.834 kWH /yr and there is no capacity shortage It is also seen that unmet electric load is aprox. Zero and payback period is 10 years. The levelized cost of energy is only 21 BDT. However, as the consideration of our proposed system components was done optimistically for the desired location Rangamati of Bangladesh, further detailed economic analysis is obligatory for practical implementation.

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## REFERENCES

[1] A.B. Kanase-Patil, R.P. Saini, M. P. Sharma, “Integrated renewable energy systems for off grid rural electrification of remote area”, Renewable Energy 35 2010, pp. 1342 – 1349.

[2] Rajoriya, E. Fernandez, “Sustainable energy generation using hybrid energy system for remote hilly rural area in India”, International Journal of Sustainable Engineering, May 2010,pp.1–9.

[3] Ajai Gupta, R.P. Saini, M.P. Sharma “Steady-state modeling of hybrid energy system for off grid electrification of cluster of villages”, Renewable Energy 35, 2010, pp. 520 – 535.

[4] Ahmad Agus Setiawan, Yu Zhao, Chem. V. Nayar, “Design, economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remote areas”, Renewable Energy 34,2009, pp. 374–383.

[5] Akella A.K., Sharma M.P. and Saini R.P., “Optimum utilization of renewable energy sources in a remote area”, Renewable and Sustainable Energy Reviews 11, 2007, pp. 894–908.

[6] Surekha Manoj, Puttaswamy Palahalli Srinivasaiah, “Estimation and Cost Effective Analysis of Hybrid-Wind/PV Generation for Rural/Remote Electrification”, International Journal of Emerging Technology and Advanced Engineering, December 2012, Volume 2, Issue 12, pp. 740–745.

[7] Duffe J.A, Beckman W. A.,” Solar Engineering of Thermal Processes”, New York: John Willey and Sons, 1980.

[8] Nguyen Cong Van, A study of the potential of renewable energy sources and its application in Vietnam, Renewable Energy Elsevier, Volume 9, Issues 1–4, September–December 1996, Pages 1161–1164, http://www.sciencedirect.com/science/article/pii/0960148196884849.

[9] M.A. Elhadidy, S.M. Shaahid, Promoting applications of hybrid (wind+photovoltaic+diesel+battery) power systems in hot regions, Renewable Energy, Elsevier, Volume 29, Issue 4, April 2004, Pages 517–528, http://www.sciencedirect.com/science/article/pii/S0960148103002805.

[10] Fernando Valencaga, Pablo F. Puleston and Pedro E. Battaiotto, “Power Control of a Solar/Wind Generation System Without Wind Measurement: A Passivity/Sliding Mode Approach”, IEEE Trans. Energy Conversion, Vol. 18, No. 4, pp. 501-507, December 2003.

[11] Deepak Kumar Lal, Bibhuti Bhusan Dash and A. K. Akella, Optimization of PV/Wind/Micro-Hydro/Diesel Hybrid Power System in HOMER for the Study Area, International Journal on Electrical Engineering and Informatics”, Volume 3, Number 3, 2011.

[12] W. D. Kellogg, M. H. Nehrir, G. Venkataramanan, and V. Greez, “Generating Unit Sizing and Cost Analysis for Stand-alone Wind, Photovoltaic and Hybrid Wind/PV Systems”, IEEE Trans. EnergyConversion, Vol. 13, No. 1, pp. 70-75, March 1998.

[13] Kurozumi, Kazuhiro et al, “Hybrid system composed of a wind power and a photovoltaic system at NTT Kumejima radio relay station”, INTELEC, International Telecommunications Energy Conference 1998, pp. 785-789.

[14] Riad Chedid and Saifur Rahman, “Unit Sizing and Control of Hybrid Wind-Solar Power Systems”, IEEE Trans. Energy Conversion, Vol. 12, No. 1, pp. 79-85, March 1997.

[15] Francois Giraud and Zyiad M. Salameh, “Steady-State Performance of a Grid-Connected Rooftop Hybrid Wind-Photovoltaic Power System with Battery Storage”, IEEE Trans. Energy Conversion, Vol. 16, No. 1, pp. 1- 7, March 2001.

[16] Debajit Palit and Akanksha Chaurey, Off-grid Rural Electrification Experience fromSouth Asia: Status and Best Practices,TERI, New Delhi,01 September 2011,Version: Final, http://www.academia.edu/4172298/WP1-_South_Asia_off-grid_experience.

[17] Sanjoy Kumar Nandia, Himangshu Ranjan Ghoshb, “Prospect of wind–PV-battery hybrid power system as an alternative to grid extension in Bangladesh Energy” ,Energy, Elsevier, Volume 35, Issue7,July2010,Pages:3040–3047, http://www.sciencedirect.com/science/article/pii/S0360544210001738.

[18] S. Rehman, I.M. El-Amin, F. Ahmad, S.M. Shaahid, A.M. Al-Shehri, J.M. Bakhashwain, A. Shash, “Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant”, Renewable and Sustainable Energy Reviews,Elsevier,11 (2007) 635–653, http://eprints.kfupm.edu.sa/524/1/feasibility_study.pdf