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EVALUATION OF THE TECHNO-ECONOMIC OPPORTUNITIES OF PV/WIND/DG/BATTERY HYBRID SYSTEM FOR YEKATERINBURG, RUSSIA

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Russia's sources of electricity generation have been mainly from fossil fuels duel to the country's abundant hydrocarbon resources, and nuclear power plants. The country has huge renewable energy potentials which are yet to be fully developed. This study evaluated the techno-economic potential of a PV/Wind/DG/Battery system for integration in Yekaterinburg and other rural areas around that enclave. The Hybrid Optimization of Multiple Energy Resources software was used in the simulation of the system, some financial metrics such as levelized cost of energy (LCOE) and the net present cost (NPC) were used in the analysis. Results from the monthly electricity generation indicate that a total of 75,469 kWh/year of electricity was produced from the hybrid system. The PV system produced 29,405 kWh/year representing 39% of the total electricity generated in a year. The wind system also produced 23,291 kWh/year which also represent 30.9% of the total electricity generated per annum, whiles the DG system produced some 22,773 kWh/year representing 30.1% of the total electricity generated by the hybrid system. An excess electricity of 2,353 kWh/year was generated which represents about 3.12% of the entire annual generated electricity. The system recorded an LCOE of 0.356 $/kWh, NPC of $255,478.80 and an operating cost (OC) of $9,409.72. The obtained results will be too expensive if implemented using the selected financial conditions. However, a sensitivity analysis conducted indicates that the cost of energy can be significantly reduced if some selected financial variables are changed.

Keywords: Techno-economic analysis; cost of energy; Russia; renewable energy; HOMER.

ОЦЕНКА ТЕХНИКО-ЭКОНОМИЧЕСКИХ ВОЗМОЖНОСТЕЙ ГИБРИДНОЙ СИСТЕМЫ PV / WIND / DG / BATTERY ДЛЯ ЕКАТЕРИНБУРГА, РОССИЯ

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Источниками производства электроэнергии в России являются в основном ископаемые виды топлива, богатые углеводородными ресурсами страны и атомные электростанции. Страна обладает огромным потенциалом возобновляемых источников энергии, которые еще предстоит полностью освоить. В этом исследовании оценивался технико-экономический потенциал системы PV/ Wind / DG / Battery для интеграции в Екатеринбург и другие сельские районы вокруг этого анклава. При моделировании системы использовалось программное обеспечение «Гибридная оптимизация нескольких энергетических ресурсов», при анализе использовались некоторые финансовые показатели, такие как приведенная стоимость энергии (LCOE) и чистая приведенная стоимость (NPC). Результаты ежемесячного производства электроэнергии показывают, что в общей сложности 75 469 кВт*ч / год электроэнергии было произведено с помощью гибридной системы. Фотоэлектрическая система произвела 29 405 кВт / ч в год, что составляет 39% от общего объема электроэнергии, произведенной за год. Ветровая система также произвела 23 291 кВт*ч / год, что также составляет 30,9% от общего объема электроэнергии, вырабатываемой в год, в то время как система ДГ произвела около 22 773 кВт*ч / год, что составляет 30,1% от общего объема электроэнергии, вырабатываемой гибридной системой. Было произведено избыточное количество электроэнергии в размере 2353 кВт*ч / год, что составляет около 3,12% от всей годовой выработки электроэнергии. Система зафиксировала LCOE в размере 0,356 доллара США / кВт*ч, NPC в размере 255 478,80 долларов США и эксплуатационные расходы (ОС) в размере 9 409,72 долларов США. Полученный результат будет слишком дорогим, если будет реализован на выбранных финансовых условиях. Однако проведенный анализ чувствительности показывает, что стоимость энергии может быть значительно снижена, если некоторые выбранные финансовые переменные будут изменены.

Ключевые слова: технико-экономический анализ; стоимость энергии; возобновляемая энергия; HOMER.

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Publications: more than 450 scientific works, including 5 monographs, 80 inventions,

Hirsch Index -13.

Introduction

Access to affordable, sustainable and reliable energy is considered as a critical driving force in the lives of people as it has a significant impact on the economy and health of a country [1, 2]. Fossil fuel produces close to 80% of the world's primary energy demand and consumption is projected to grow by 2.3% per annum from 2015 to 2040, which is expected to increase the emission of greenhouse gases (GHG) in the atmosphere. The result from the emissions of such gases is the increase in average global temperature which has a dangerous effect on global climatic conditions and can cause heat waves, droughts and heavy rainfalls which comes with flooding and destruction of properties [3]. The leadership of the world are now moving towards a more sustainable and reliable sources of energy generation to safeguard the environment and the economies of the various countries [4].

Several researches have conducted studies on the techno-economic potential of different hybrid systems for different countries to assess their ability to be integrated into the various countries energy generation systems. Ansong et al. [5] assessed the techno-economic potential of a hybrid system for a mine in an off-grid community in Ghana. Agyekum and Nutakor [6] evaluated the feasibility of a stand-alone hybrid system for the southern part of Ghana. Elkadeem, et al. [7] also analyzed the feasibility of a hybrid renewable energy system in Dongola, Sudan for providing electricity in agriculture and irrigation areas.

Russia has several renewable energy potentials; however, the development of these resources is rather on a slower side mainly due to the country's huge fossil fuel reserves [8]. This paper evaluated the techno-economic potential of a hybrid energy system consisting of a photovoltaic (PV) wind, diesel generator and a battery for a possible integration at Yekaterinburg in the Sverdlovsk region in Russia. The objective of this study is to assess the bankability of integrating hybrid systems in off-grid areas in the Sverdlovsk region in Russia. The study has four sections, section 2 presents the methodology and materials adopted for the study, section 3 covers the results and discussions from the simulations and section 4 presents the conclusion.

List of symbols	
NPC	Net Present Cost
OC	Operation Cost
DG	Diesel Generator
GHG	Greenhouse Gases
PV	Photovoltaic
LCOE	Levelized Cost of Energy
CRF	Capital Recovery Factor
kWh	kilowatt Hour
$/kWh	Dollars per kilowatt Hour

1. Description of study area

Yekaterinburg is a Russian city in the east of the Ural Mountains, it is located on latitude 56.8431° N and 60.6454° E [9], with a population of about 1.5 million as at 2018 [10]. The city has a generally very cold weather condition. The weather characteristics of the studied location is presented in Fig. 1 and Fig. 2.

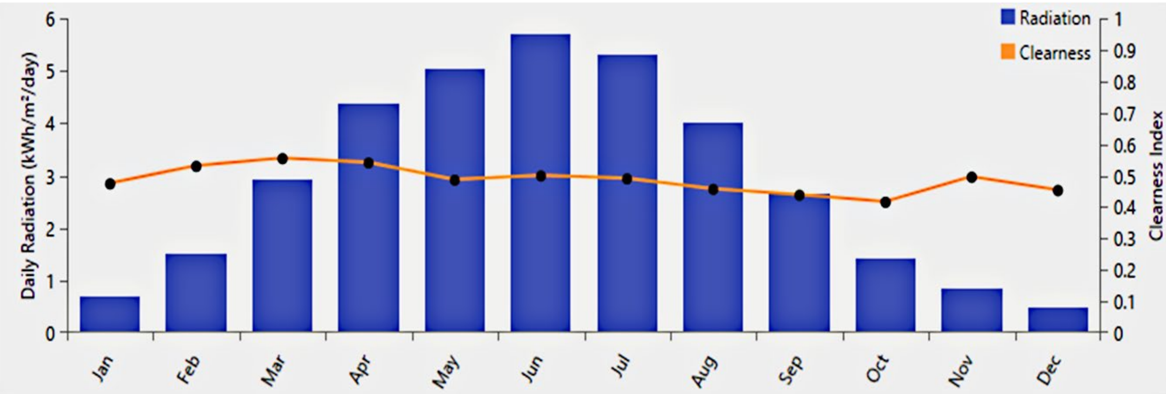

Fig. 1. Solar irradiation characteristics of Yekaterinburg.
Рис. 1. Солнечные характеристики облучения Екатеринбурга.

Fig. 2. Wind speed characteristics in Yekaterinburg.
Рис. 2. Скоростные характеристики ветра в Екатеринбурге.

2. Methodology

The HOMER Pro® software was used in the simulation of the techno-economic potential of a PV/Wind/DG/Battery system. HOMER is a microgrid software use globally to optimize and design power plants for villages, island communities, campuses and military bases etc. [6]. The levelized cost of energy (LCOE) was used to evaluate the bankability of the modelled system. The LCOE is the total sum of the cost during the project's lifetime divided by the unit electricity generated in the entire lifetime of the project [11]. The mathematical relation for calculating the LCOE is indicated in Eq. (1) [11].

$$LCOE = \frac{\sum_t^T \left[\frac{Investment+OPEX+Decommisioning+Fuel\ cost}{(1+r)^t}\right]}{\sum_t^T \frac{Electricity}{(1+r)^t}}; \quad (1)$$

where, T is the expected lifetime of the plant and r is the discount rate.

The net present cost (NPC) is the system's present value of the entire cost which include the installation and operation cost during the lifetime of the project minus the present value of the entire income accrued during the lifetime of the project. HOMER calculates the NPC using Eq. (2) and Eq. (3) [12].

$$NPC = \frac{C_{ann,\ tot}}{CRF(i, R_{proj})}; \quad (2)$$

where, $CRF\ (i, N)$ denotes the capital recovery factor, $C_{ann,\ tot}$ is the total annualized cost, i is the annual real interest rate, N is the number of years and R_{proj} is the lifetime of the project.

$$CRF_{(i,N)} = i(1+i)^N \Big/ ((1+i)^N - 1) \quad (3)$$

The following are the financial parameters of the various components used in the analysis: the Schneider Conext CL25000 E kW PV module was selected for the simulation, using a capital cost of 2000 $/kW, replacement cost of 2000 $/kW and O&M cost of 40 $/kW [6]. The Eocycle EO25 Class IIA wind turbine was used, using a capital cost of 1500 $/kW, replacement cost of 1500 $/kW and O&M cost of 0.030 $/year [13]. Surrette 4KS 25P battery was used at a capital cost of 200 $/kWh [6]. A discount rate of 10% was used. A diesel cost of 0.75 $/L was used since that was the cost of diesel in Russia as at the time of the simulation [14]. Fig. 3 shows the proposed hybrid power plant for the community.

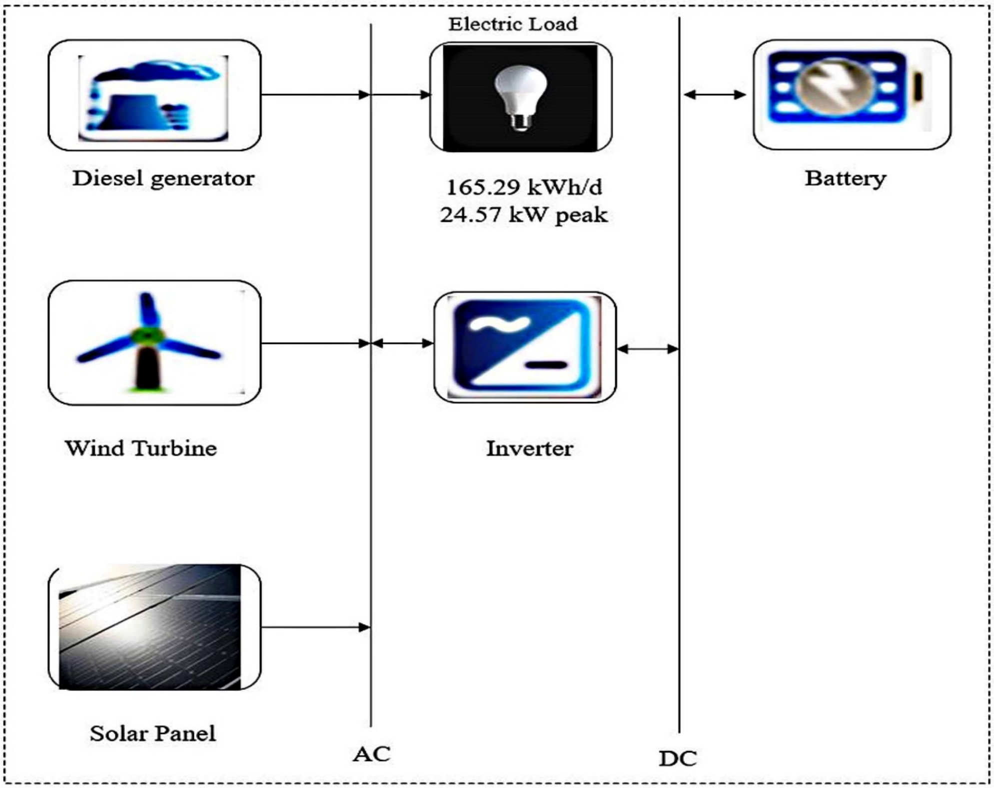

Fig. 3. Proposed hybrid system.
Рис. 3. Предлагаемая гибридная система.

3. Results and Discussions

This section provides the techno-economic analysis on the simulated power plant as well as a sensitivity analysis on some technical and economic parameters used for the modelling.

3.1. Electricity production

The peak load demand for the community as suggested by the HOMER software is 24.57 kW and a daily electricity demand of 165.29 kWh/d. Data from the simulation indicates that, the winter periods has the highest load demand, mainly because of the need to provide electricity for heating during that period. The months of May to September has a relatively low load because of the summer period. The results also indicated that most load demand is between 18 and 21 hours when everybody is at home and electricity is needed for lighting and other electronic gadgets. Demand falls after 21 hours through to 7 hours when people retire to bed, it however increases to about 10 kW during the day when people are at work and therefore need power at work.

Fig. 4 shows the monthly electricity generation from the various components of the hybrid system. Results from the monthly electricity generation indicates that a total of 75,469 kWh/year of electricity was produced from the hybrid system. The PV system produced 29,405 kWh/year representing 39% of the total electricity generated in a year. The wind system also produced 23,291 kWh/year which also represent 30.9% of the total electricity generated per annum, whiles the DG system produced some 22,773 kWh/year representing 30.1% of the total electricity generated by the hybrid system. An excess electricity of 2,353 kWh/year was generated which represents about 3.12% of the entire annual generated electricity. A renewable fraction of 62.3% was achieved, which is good for the system and reduction of GHG emissions. The generator worked most during the winter seasons which is expected because there is virtually no sunshine during that period of the year.

Electricity production from the PV system was highest in the middle of the year when sunshine is high. The turbine operated mostly below its capacity, it generated more power in the afternoons when wind speed is high and falls to 6 kW and below during the evenings and nights.

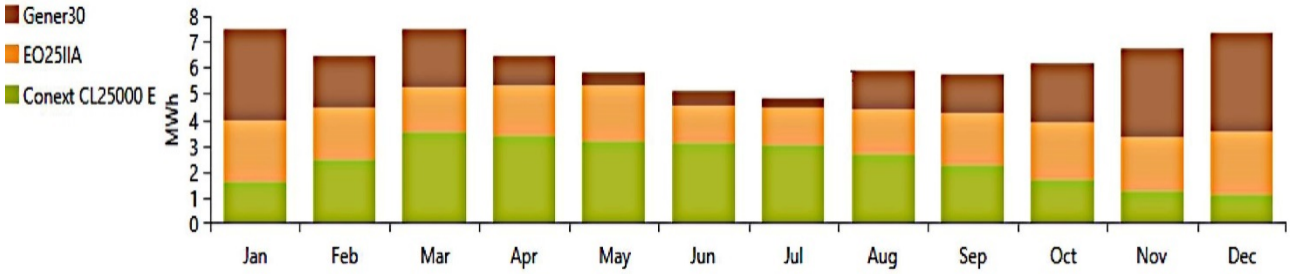

Fig. 4. Monthly electricity generation from the various components.
Рис. 4. Ежемесячное производство электроэнергии из различных компонентов.

3.2. Economic Analysis

The system recorded an LCOE of 0.356 $/kWh, NPC of $255,478.80 and an operating cost (OC) of $9,409.72. Data from the analysis indicates that the renewables constituted 46.13% of the total NPC whiles the DG, Battery and converter took 53.87% of the NPC. In comparing the current case (PV/Wind/DG/Battery) system with a base case (diesel generator) to ascertain the optimal system for electricity generation, the base system recorded an NPC of $521,683 and an initial capital of $30,000 whiles the current case scenario recorded an NPC of $255,479 and an initial capital of $143,778. From this data, it shows clearly that whereas the base case may be cheaper in terms of initial cost, its cost of operation and maintenance is expensive. The NPC of the base case is about 49% more than the cost of running and maintaining the current system, indicating that the current case will be a better option for power generation at the selected site. Table 1 shows the financial analysis for the current system. Data from the financial analysis shows that such a project will be viable but very expensive to the consumer considering the obtained LCOE. An investor will recoup all the invested capital within a short period of 3.68 years, the discounted payback of 4.34 years is still good for an investment.

Table 1

Financial analysis of the current system

Таблица 1

Финансовый анализ действующей системы

Description	Value
Present worth, $	266,204
Annual worth, $/year	22,425
Return on investment, %	23.8
Internal rate of return, %	27.3
Simple payback, years	3.68
Discounted payback, years	4.34

3.3. Sensitivity analysis

A sensitivity analysis was conducted to verify the possible effect of certain parameters on the bankability of the project. This is a very critical step in feasibility study since it offers policymakers and investors the opportunity to know the factors that they need to pay close attention to in order to make the investment a success. The cost of diesel, discount rate and wind speed are some of the parameters varied to ascertain their impact on the cost-effectiveness of the modelled project. Data from the analysis shows that the cost of fuel and discount rate has a significant effect on the LCOE of the PV/Wind/DG/Battery system, decreasing the discount rate to about 5% at a fuel cost of 0.44 $/L could decrease the LCOE to about 0.26 $/kWh. Wind speed has proven to have a significant effect on the cost effectiveness of the system, increasing the hub height of the turbine increases the wind speed. For instance, increasing the wind speed to 7 m/s at a fuel cost of about 0.40 $/L could positively reduce the LCOE to about 0.16 $/kWh which is a significant reduction from the LCOE obtained from the original simulation. The discount rate also affects the NPC very significantly, as increasing discount rate decreases the NPC.

Conclusion

This paper evaluated the techno-economic potential of a PV/Wind/DG/Battery system in Yekaterinburg, a city in Russia, for a possible integration into the electricity generation mix for the area. The results obtained from the simulation using some current economic factors in the Russia territory such as inflation rate of 3%, diesel fuel cost of 0.75 $/L and weather conditions at the selected site indicates that, such a project will be too expensive for the electricity consumer should it be implemented under the selected conditions. An LCOE of 0.356 $/kWh was obtained, however, results from the sensitivity analysis conducted shows that, the project could be bankable and relatively cheaper if certain parameters used for the analysis are changed. The results obtained from the study indicates that both policymakers and investors have a crucial role in making such a project viable, i.e. cheaper for the consumer. Several interventions such as subsidies on fuel from government and the creation of a conducive economic environment can make such project bankable.

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