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Designing and Analyzing Hybrid Renewable Power Generation for Dekembare National Law Enforcement Training Center, 2023

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A B S T R A C T

The off-grid hybrid systems are becoming effective, reliable, sustainable and environmental protective electricity supply system especially for communities where grid extension is not appropriate. The increasing demand for conventional energy sources like coal, natural gas and oil is forcing people towards the research and development of renewable energy sources or non-conventional energy sources. Hybrid renewable energy system is the combination of two naturally occurring energy sources to provide sufficient and sustainable energy to the people. Therefore, the aim of the project is to design and analyze wind turbine, photovoltaic, diesel generator, battery and inverter by simulating to optimize the demand of power means for Dekemhare National Law Enforcement Training Center (DNLETC). Hybrid system is being used to supply electricity to possible coverage areas in all aspects like, reliability, sustainability, and environmental protections, especially for communities living far from the grid source of power. The main power generating sources were tested as a combination of wind and solar energy along with the battery and diesel generator as a backup. Data was collected for designing and analyzing purpose. Therefore, the following procedures have been followed accordingly. First, the collected data which is the wind speed along with the wind direction and daily radiation of the project site was analyzed and passed through a number of calculations following the right procedure to obtain the required data for designing the hybrid energy system. Secondly, based on the obtained results wind turbine, solar PV, battery, diesel generator components were selected accordingly. Besides the selection, wind blade that works properly within the site was designed to obtain higher efficiency.

The project was capable to generate a power of 1MW in which 70% from wind and 30% from solar. The generator was already available at the site, so we integrated the generators to our system as per required. The whole system was controlled and regulated using the micro grid controller which makes the system more reliable, accurate and easily regulated. A multi-power generation of a renewable hybrid power plant designed for Dekemhare National Law Enforcement Training Center was found to be cost effective and reluctant emitter of harmful gasses which makes it feasible for implementation.

Keywords: Renewable energy, hybrid technologies

1. Introduction

The inevitable growth of energy consumption leads to an increase in fossil fuel use for energy production. The dependency on fossil fuels for obtaining energy has increased up to a great extent due to the increase in population and the great success achieved in industrialization. However, to minimize people's dependency on fossil fuels, researchers are focusing more on using renewable energy for power generation systems. Hence, to avoid the threatening effect of fuel-based energy, renewable energy system is becoming the choice of means of energy which are favorable to the climate and the health of human being [1].

Renewable energy is the energy sources naturally replaced on a human timescale, such as tides, waves, sunlight, wind, and geothermal energy. A hybrid renewable energy system is one of the eco-friendly power generating systems which normalizes the supply-demand mismatch that occurs in a single renewable producing unit. Various components in the hybrid renewable energy system make the design a bit complex but sustainable. Hybrid systems have been attracting to supply electricity to areas in need with all possible aspects like reliability, sustainability and environmental protection, especially for communities living ‘in areas where grid extension is costly for installation. A hybrid renewable set-up indicates that various combinations based on renewable sources could be applied simultaneously to cater energy in the form employed in an off-gird supporting with battery storage and diesel generator as backup systems [2].

Wind and solar energy will be considered as primary sources to supply electricity directly to the load and to charge the battery bank when an excess generation has occurred; however, in peak demand times, diesel generators could also be engaged. The community's load will be suggested for lighting, water pumping, school and health clinic equipment load, and social services. The design of the hybrid power system set-up, the simulation and optimization will be based on the electricity load, climatic data sources, the economics of the power components and other parameters in which the use of fossil fuels has to be minimized to select an economically feasible power system. Moreover, other parameters like a capacity shortage, excess electricity, and diesel fuel consumption will also be considered to check the technical capability so as to select a system [3].

Eritrea's government is striving to apply the growth and transformation plan strategy in renewable source of energy system since it has a huge potential of wind and solar sources of energy that can cover the electricity demand in the country. Eritrea lies between latitudes of 12^o and 18^o north of equator and 34^0 and 45^0 east longitudes [6]. This shows there is a considerable amount of renewable energy sources that can be accounted for and part of it would be exploited for electricity generation. Therefore, the main purpose of the project is to get reliable electricity from the solar wind hybrid generation system to the user with an uninterrupted electrical power supply and an affordable cost.

The system may require working components such as wind turbine, solar panel, charge controller, battery, inverter and sensors. The supply of improved electricity services has benefits of creating new job opportunities, simplify life and create a good job atmosphere. Currently, the nation is consuming too much fuel for generating electric supply to generators in Hirgigo Power Plant, which is cost-effective means of energy generation and remains below required. Thus, this capacity shortfall shows the country's electricity supply is in threat. Although energy demand is growing rapidly in the country, renewable energy sources haven't been exploited yet. Nevertheless, for sustainable supply, fuel source has to support with other local available renewable energy sources like solar, geothermal, and wind sources.

1.1 Background

Almost all Eritrean communities depend on fuel-wood for the daily energy demands, causing incredible deforestation and degradation of the eco-system. Moreover, there is a challenge to supply electricity to the population because of two reasons. First, there is no enough power generation to fulfill the current power demand. Second, even with enough power generation, installing a grid system to each household is challenging due to their geographical locations and economic constraints. The challenge, therefore, is the supply of sustainable electricity service without long waits for grid extension and reliance on fossil-based power plants [7].

The demand and energy exploitation is rising in Eritrea; to fulfill the country's ever-increasing demand, the power generation system must expand to exploit the renewable sources which have direct synergy with poverty alleviation in the nation. Certain fundamental services that should be provided to a particular community are electricity, water supply, communication; transportation, health care, and education are mandatory needs for any community to escalate out of poverty. Thus, reliable electricity is a prerequisite to cater these services [8].

Electrifying the remote areas of Eritrea by extending transmission lines from the utility grid to the remote communities is labor, time, and capital intensive. As a result, many communities in Eritrea still live without access to electricity either from the utility grid or independent renewable energy generated electricity. Hence, this study is designed to assess the potentials of wind and solar resources, which are then, followed by load estimation and design of the hybrid systems to mitigate the current shortage of electricity in the study site.

The total grid electricity generation capacity in Eritrea is about 151 megawatts but due to aging, deterioration, and lack of spare parts and maintenance, available capacity is lower to 35 MW, with national electricity access rate estimated of about 38% of the population [6]. Moreover, the power plant depends on imported an oil-fired thermal generator that has cost effectiveness, high dependency and insecurity of supply. This hybrid renewable system project will be a good start to mitigate the gap with immediate environmental benefits; as fossil fuel consumption will be reduced. Therefore, the proposed project will have a potential to reduce the current approximately $561,565.00 cost per year of 33,090 liters of diesel, lubricant, and oil ($47,876.60) and 12,988,262kw of grid ($513,688.40) by about 70% [9].

The project will also replace the unreliable and inadequate grid power supply system that has been identified as one of the most significant impediments to the growth of the training institution. The teaching learning process in the campus will be enhanced without interruption. Aside from the immediate economic and work benefits to the training institution, the project will help to minimize carbon emissions in the surroundings. Above all, the project will increase the capacity to plan, design, install, operate and maintain hybrid energy systems in the country.

1.2 Literature Review

In order to gather reasonable information about renewable energy resource potentials of the country, hybrid energy systems, and rural electrification techniques applying combined resources, a detailed study of this all was needed. Different research efforts for the application of renewable energy options have been conducted to access renewable energy resource potentials and stand-alone hybrid systems [11]. Recently, energy storage techniques and hybrid power systems have been the focal point of many energy researches and development activities.

Sen and Bhattacharyya analyzed the optimum strategy for hybrid technology to meet the electricity requirement of an isolated rural zone in India [5]. Hydropower, PV, wind turbines and biodiesel generators energy source were envisaged economically more profitable designed system compared to grid extension. From the same sources, seven different system configurations and a comparison between the autonomous PV/Diesel/Wind system with and without storage were examined in Johor Bahri, Southern Peninsular Malaysia. The proposed designs were not competitive against the only configuration, and they could mitigate up to 34.5% of greenhouse gasses [12].

S. Rehman et al., (2007) presented a feasibility study of the hybridizing of some wind turbines to an existing off grid diesel power plant in the northern rural area of the Kingdom of Saudi Arabia. The study was basically to minimize the running cost of diesel generators by combining them with wind turbines and, accordingly to mitigate environmental pollution. Sensitivity analysis was also made by taking sensitive parameters such as wind speed which can affect the power system during its lifelong. The simulation result shows that retrofitting the wind turbine to the existing diesel generator was not feasible for wind speeds less than 6m/s and fuel prices of $0.1/litter [13].

1.3 Data collection

After following the right procedures of wind data collection, wind data evaluation using the necessary calculation parameters and statistical probability distribution functions, we have come up to proceed with the results or outcomes it has brought. Figure 1 provide with the statistical probability tables and graphs for the number of provided data collected from the Ministry of Mining and Energy (MOME) for the years of 2000-2005.

As per the steps of our procedure we were required to check the data's provided for they have to be measured every 10 minutes throughout the complete year. These for the years we have come across from 2000-2005 some of the data's provided from (MOME) were missing. Thus, we have had to fill the missing data to proceed with the following procedures of assessing and presenting the results it has come up to.

We have used the techniques of AI (Artificial intelligence) technology to fill those missing data except for the year 2005. The second technique we used was interpolating the data for few missing data as per the indication it presents itself with. However, to obtain an accurate and not biased results for the assessment of the data's we have decided and selected to use the data for the year 2005 for all our incoming steps of statistical analysis graphs and tables that follows.

Data wind speed in the year 2000

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m	Power density
January	6.366	9.511	13.5	21.106	2.734	4.140	0.8260
February	6.284	9.408	13.5	21.106	2.614	3.999	0.7671
March	5.936	8.904	13.5	21.106	2.567	3.959	0.6766
April	5.343	8.079	14.91	22.198	2.653	4.109	0.6398
May	6.441	9.822	14.91	22.198	2.746	4.298	1.0214
June	6.202	9.525	14.91	23.812	2.753	4.345	0.9137
July	6.156	9.395	16.37	26.654	2.660	4.194	0.6791
August	5.954	9.091	16.37	26.673	2.592	4.082	0.6359
September	5.340	8.141	16.37	26.673	2.648	4.169	0.6948
October	5.918	8.899	16.37	26.673	2.653	4.149	0.6917
November	5.900	8.878	16.37	26.673	2.622	4.091	0.6177
December	5.718	8.564	16.37	26.673	2.599	4.046	0.5736
Annual	5.963	9.018	15.287	24.295	2.653	4.132	0.7281

Data wind speed in the year 2001

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m	Power density
January	6.621	9.919	12.07	18.343	2.107	3.285	0.7893
February	6.042	9.030	12.52	19.816	2.407	3.707	0.7281
March	5.082	7.641	12.69	20.369	2.570	3.971	0.5342
April	5.315	8.033	13.49	20.369	2.594	4.030	0.5933
May	5.854	8.940	13.73	23.024	2.694	4.230	0.8677
June	6.030	9.139	14.72	23.295	2.626	4.110	0.6666
July	5.734	8.734	14.72	23.295	2.538	3.964	0.5455
August	5.388	8.241	14.72	23.295	2.433	3.806	0.4352
September	5.269	8.036	14.72	23.295	2.441	3.827	0.5693
October	5.929	8.936	14.72	23.295	2.441	3.804	0.6579
November	5.713	8.584	14.72	23.295	2.404	3.735	0.5307
December	5.606	8.393	14.72	23.295	2.362	3.661	0.4816
Annual	5.715	8.636	13.962	22.082	2.468	3.844	0.6166

Data wind speed in the year 2002

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m	Power density
January	5.369	8.030	9.928	15.592	1.544	2.406	0.4042
February	5.499	8.223	9.956	15.592	1.674	2.624	0.4646
March	5.055	7.595	10.274	15.816	1.774	2.814	0.4150
April	5.187	7.849	10.699	17.013	1.878	3.004	0.4907
May	5.460	8.336	11.254	18.122	2.004	3.238	0.6222
June	5.517	8.422	11.46	18.679	1.999	3.232	0.5286
July	5.716	8.752	15.59	24.720	2.059	3.315	0.6443
August	5.837	8.928	17.4	27.089	2.081	3.340	0.6316
September	5.759	8.784	17.4	27.089	2.209	3.537	0.8139
October	5.973	9.000	17.4	27.089	2.292	3.626	0.7580
November	5.764	8.647	17.4	27.089	2.305	3.622	0.6022
December	5.964	8.922	17.4	27.089	2.324	3.632	0.6608
Annual	5.592	8.457	13.846	21.784	2.012	3.199	0.5863

Data wind speed in the year 2003

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m
January	5.931	8.877	12.57	19.002	2.199	3.389
February	5.523	8.244	12.57	20.199	2.380	3.637
March	5.677	8.524	14.1	21.696	2.501	3.863
April	5.518	8.362	14.29	21.696	2.630	4.091
May	5.376	8.209	14.29	21.696	2.710	4.246
June	6.221	9.480	14.29	22.537	2.688	4.221
July	6.034	9.196	17.24	28.418	2.588	4.056
August	5.395	8.227	17.24	28.418	2.508	3.927
September	5.788	8.818	17.24	28.418	2.565	4.023
October	6.384	9.631	17.24	28.418	2.594	4.045
November	6.081	9.137	17.24	28.418	2.600	4.038
December	5.709	8.545	17.24	28.418	2.562	3.970
Annual	5.803	8.771	15.463	24.778	2.544	3.959

Data wind speed in the year 2004

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m
January	5.369	8.030	9.928	15.592	1.544	2.406
February	5.499	8.223	9.956	15.592	1.674	2.624
March	5.051	7.596	12.89	20.199	1.961	3.085
April	5.538	8.376	14.63	23.000	2.212	3.490
May	6.388	9.746	14.63	23.000	2.428	3.873
June	5.432	8.307	14.63	23.000	2.338	3.741
July	6.003	9.172	14.63	23.000	2.299	3.673
August	5.644	8.620	14.63	23.330	2.270	3.618
September	5.372	8.184	14.63	23.330	2.307	3.673
October	5.851	8.817	14.63	23.330	2.374	3.743
November	5.936	8.939	14.63	23.330	2.416	3.787
December	6.026	9.038	14.63	23.330	2.422	3.785
Annual	5.676	8.587	13.704	19.725	2.187	3.458

Data wind speed in the year 2005

	Mean speed at 10m	Mean speed at 65m	Max speed at 10m	Max speed at 65m	Standard deviation at 10m	Standard deviation at 65m	Power density
January	5.158	7.701	11.04	17.155	2.245	3.391	0.4470
February	6.038	9.023	12.43	18.472	2.449	3.723	0.7048
March	5.565	8.343	12.8	20.082	2.496	3.822	0.6125
April	5.924	8.949	18.43	28.661	2.633	4.071	0.8300
May	5.636	8.594	18.43	28.661	2.706	4.222	0.7700
June	5.980	9.164	18.43	28.661	2.737	4.300	0.8593
July	5.854	8.913	18.43	28.661	2.658	4.165	0.6013
August	5.520	8.432	18.43	28.661	2.606	4.082	0.5560
September	5.515	8.420	18.43	28.661	2.618	4.110	0.6764
October	6.789	10.24	18.43	28.661	2.654	4.143	0.9880
November	6.441	9.677	18.43	28.661	2.634	4.097	0.7671
December	6.038	9.034	18.43	28.661	2.599	4.029	0.6227
Annual	5.872	8.874	16.845	26.138	2.586	4.013	0.7029

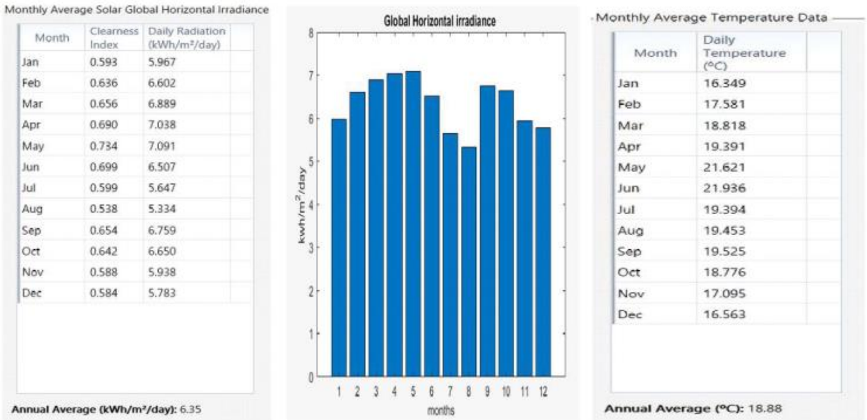
Figure 1 Data collection from the Ministry of Mining and Energy of Eritrea

1.4 Solar Energy System

After following the right procedures of solar data collection, similar to that of wind; we have come up to proceed with the results or outcomes it has brought. This following (Figure 2) will thus provide with the solar global horizontal irradiance and temperature results from the data collected from the Ministry of Mining and Energy (MOME) for the years of 2000-2005.

The Figure displays the daily irradiation and clearness index throughout the year. The annual average solar global horizontal irradiance is 6.35 kWh/m2/day. For this area the monthly solar radiation shows a more constant trend than the wind speed. To use solar irradiations for power generation the annual radiation should be above 4 kWh/ m2/ d [25].

According to NASA's prediction of the global energy resource database for the next 30 years, the average monthly air temperature at the considered site is 18.88 0C. The average monthly air temperature was obtained from NASA for the selected location and is shown in Figure [26].


Monthly Average Solar Global Horizontal Irradiance

Month	Clearness Index	Daily Radiation (kWh/m²/day)
Jan	0.593	5.967
Feb	0.636	6.602
Mar	0.656	6.889
Apr	0.690	7.038
May	0.734	7.091
Jun	0.699	6.507
Jul	0.599	5.647
Aug	0.538	5.334
Sep	0.654	6.759
Oct	0.642	6.650
Nov	0.588	5.938
Dec	0.584	5.783

Annual Average (kWh/m²/day): 6.35

Monthly Average Temperature Data

Month	Daily Temperature (°C)
Jan	16.349
Feb	17.581
Mar	18.818
Apr	19.391
May	21.621
Jun	21.936
Jul	19.394
Aug	19.453
Sep	19.525
Oct	18.776
Nov	17.095
Dec	16.563

Annual Average (°C): 18.88

Figure 2 Irradiation and CI throughout the year and monthly GHI and temperature

2. Results and Discussions

With its ability to control one turbine or an entire wind park, the ASC-4 Wind sustainable controller allows integration of wind power in any power plant. It can be used in an intelligent power or energy management system, balancing sources to cover demand while maximizing renewable power penetration.

The ASC-4 Wind is available as a fully customized solution for specific projects and is ideally suited for hybrid micro grid applications.

Opticaster adds forecasting and optimization to the Microgrid Controller for further lowering the micro grid's fuel consumption. By recording meter reading over time, Tesla's algorithms are able to forecast changes in load and solar production, enabling more efficient use of generators and enforcement of generator quiet hours.

Opticaster runs on the Tesla Site Controller alongside the Microgrid Controller. If selected, it will be enabled by Tesla during commissioning.

Figure 3 Project layout descriptions

System states during black start

In this state, no loads are powered. The micro grid AC voltage drops to zero. The DC bus of the battery system may still be energized. If this is a grid-tied micro grid, the utility breaker is also open.

Battery + Solar

In this state, the battery is the only grid-forming asset and supplies the net load. This state typically has the lowest operating cost and is therefore preferred if adequate battery power and energy are available.The Microgrid Controller automatically curtails excess PV production when either instantaneous PV power or battery state of energy is too high to prevent overcharging the battery.

Generators + solar

In this state, the net load is supplied by the generator while the battery is inactive. The Microgrid Controller automatically curtails excess solar production to prevent the generator output power from dropping below zero, which would cause the generator to trip on reverse power.

This state is temporary while the battery is out of service due to a fault or maintenance.

Battery +Generators + solar

The Microgrid Controller commands the system into this state if the solar and battery are active but they are not sufficient to meet the load. In this scenario, a generator must be dispatched to fill the gap. The battery and solar may be insufficient because:

Solar cannot power the load and the battery has discharged to the Minimum SOE.

The loads are greater than the nameplate power of the battery, so an additional swing bus source of power is needed.

The Microgrid Controller automatically curtails excess solar production to prevent sending reverse power to the generator and exceeding the battery's charge power or Maximum SOE.

Battery +Generators + solar+wind

The Microgrid Controller commands the system into this state if the solar, wind and battery are active but they are not sufficient to meet the load. In this scenario, a generator must be dispatched to fill the gap. The battery and solar may be insufficient because:

Solar and Wind cannot power the load and the battery has discharged to the Minimum SOE.

The loads are greater than the nameplate power of the battery, so an additional swing bus source of power is needed.

Real power sharing between the battery and one or multiple generators is actively managed by coordinating frequency-watt droop curves.

3. Conclusion

In this project, the detailed study of the project site to implement solar-wind hybrid power system along with the battery and generator as a backup for DNLETC was carried out. The following procedures had been followed accordingly. First, we managed to review the climatic data sources for the study site. As a result, the wind and solar potential of the site was found to be considerably high, and sufficient enough to supply the necessitate amount of energy in the current and near future energy demand for the DNLETC. Therefore, we had selected the respective perfectly suiting, easily applicable and acceptable types of wind turbines, solar PV, diesel generator, battery storage and components for project control system. Afterwards, the necessary calculations for designing and arrangement of the solar PV along with the diesel generator and battery were well performed.

Besides, the design of blades for the selected wind turbine was accomplished. In this project hybrid power system managed to produce an outcome of energy from wind power, which accounts 70%, and the solar power covers 30% of total load consumption. Therefore, to regulate and control the necessitate sum of energy was performed by the micro grid controller. At last, we have evaluated the effectiveness of the designed hybrid power system with the existing grid power systems on the main circumstances of effective reduction on the emission of harmful gases and cost estimation. Finally, we have come up to conclude that the off-grid PV/wind/battery and generator hybrid system is an environment friendly, technically and economically feasible, highly efficient, and an excellent option which provides prominent sustainable energy to the consumers.

4. Recommendations

We advocate that the next phase of this project has to be implemented and readily used on ground in order to achieve and provide prominent and sustainable energy to the consumers. Furthermore, we also have to look forward in searching sites that are rich in renewable energy sources and are capable enough to extract the amount of energy needed as per the demand load. Starting from earlier days till now the national energy strategy is working on the thermal power plant and currently working towards the standalone solar power plant system. However, this standalone system strategy is not effective as the hybrid system in fulfilling the requirements needed. So, hybrid systems should be given a higher attention as their capital investment is low, convenient, ecofriendly and an excellent provident of energy. We also recommend for the Ministry of mines and energies to use this project as a platform to implement and further grow it into a larger power plant project in providing and sustaining optimum amount of energy for the whole country.

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