International Journal of Science, Technology and Management (IJSTM) ISSN (online): 2321-774X
Volume 10, Issue 1, 2023

Optimal Sizing and Cost Assessment of Solar, Wind and Hydro Hybrid Energy System

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Abstract: To effectively address the difficulties posed by climate change, energy security, and sustainable development, It is now imperative to make use of alternative and renewable forms of energy into the energy landscape as it currently exists. Hybrid Renewable Energy Systems (HRES) have emerged as a possible option by synergizing the capabilities of several renewable sources to overcome the constraints of each individual source and boost the efficiency of the system. This abstract offers a summary of the most important features pertaining to HRES, such as its description, components, benefits, problems, and current achievements in the field. This paper presents the hybrid energy system sizing and cost assessment analysis. Three different cases have been studied for the better renewable energy fraction value at cost minimization.
Key words: hybrid energy, micro grid, renewable fraction

Introduction:

Energy is an essential fundamental aspect of all activities that involves human and the primary force behind the progression of both the economy and society. A connection can also be made between access to electricity and rural development in poor countries. Conventional fuels like coal, oil, and natural gas are the primary types of energy that are used in the generation of electricity. Other conventional sources of energy include solar, wind, and hydropower. These resources are recognized as the essential pillar upon which the growth and rural development of every nation is built. Despite the fact that these sources are utilized in rural regions, the production of power is expensive due to the many hurdles that exist. In addition, the continued use of conventional sources of energy to generate the electricity results in rapid depletion of these sources and has negative consequences on the environment. Alternative energy sources, such as solar, hydro, wind, and tidal power, as well as others, are collectively referred to as renewable energy sources (RES). These reasons compelled the adoption of alternative energy sources. The generation of energy that occurs through the use of RES is referred to as distribution generation. The author [1] discussed the many difficulties that may arise in the future for the use of Renewable energy in distribution systems. The term "hybrid renewable energy system" (HRES) refers to a power generation setup that uses at least two different types of renewable energy sources. In spite of the significance of electrical energy, many outlying regions in developing countries either do not have access to power or do not have electricity available to them. Despite the fact that there are so many regulations and plans in place, India has only attained an overall electrification rate of 67% as of today [2]. In addition to this, it has come to our attention that none of the rural communities are receiving electricity of a sufficient quality, and it is estimated that around one-third of the population may be struggling with the issue of poor electrification or extremely limited access to electricity [2]. The purpose of a distributed energy storage system, or DESS, in a micro grid network is to store energy for use either when the cost of electricity on the main distribution grid is low. The reference [3] goes over the various plans that are associated with the technologies that store energy. When this occurs, DESS can also function as an energy source since the demand for electricity is greater than the production of electricity. Energy arbitrage, often known as buying power from the main utility grid at a time when prices are low and selling it later when prices are high, is something that may be accomplished with the use of DESS [4]. For the purpose of energy storage, a wide variety of DESS are available and can be utilized. Some examples of these are battery banks, flywheels, super capacitors, compressed air energy storage, and others. In the next subsection, various DESS are discussed in greater detail. . Wind power has been the most rapidly growing and successful alternative energy source in recent years. It was mentioned in reference [5] that a comprehensive study of smart grids and micro grids using a variety of RES was conducted. According to reference [6], it was noted that According to the Renewable 2019 Global Status Report [7], roughly 17 nations generated more than 90 percent of their total electricity from RERs in 2017. [8] Kumar et al. emphasized that it is crucial to evaluate solar capacity for applications involving renewable energy.

Area Specification for Study

The right site selection is the most crucial thing to consider when it comes to the effective and efficient planning of a micro grid. For the micro grid network that is based on renewable energy, there needs to be appropriate environmental parameters that are acceptable for RES. In the course of our research, we determined that the best place to set up a micro grid network would be in the Sundargarh area of the Indian state of Orissa. Within the Sundargarh district lies a small block known as Himgir, which is designated for the planning of micro grids in rural areas.

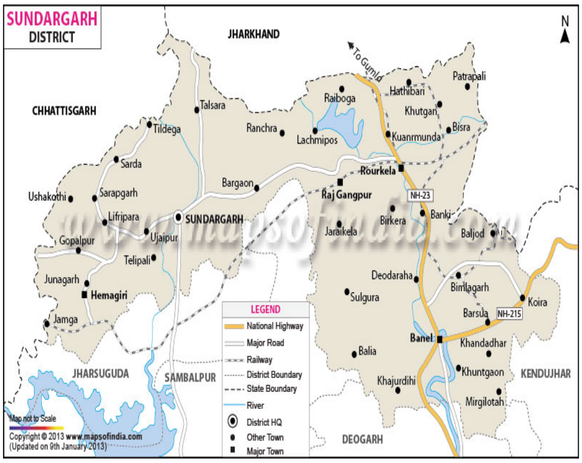

Figure-1. Study area district Sundargarh in Odisha State of India

III. Result and Discussion

Solar energy System

The first scenario is a micro grid that is powered by solar photovoltaics, distributed generation, batteries, and converters. The results of the suggested study are achieved, and they are based on the selection of the optimal renewable portion (RF), as well as the values of operational cost, LCOE, and TNPC. Table 1 presents the sizing information as well as the various cost figures for solar green micro grid systems:

S. No.	Renewable Fraction (%)	Sizing of Renewable Energy Resources				Operating cost ($/year)	Levelized Cost of Energy ($/kWh)	Total Net Present Cost ($)
		Solar PV (KW)	Diesel Generator (KW)	Battery (Qty)	Converter (KW)			
1	10	200	600	-	500	754814	0.792	10993250
2	20	200	500	4000	1000	577305	0.833	11568393
3	30	400	500	-	500	566194	0.697	9676358
4	40	400	500	4000	1000	504144	0.847	11753148
5	50	800	500	-	500	488069	0.787	10917659
6	60	800	500	2500	500	396476	0.828	11496788
7	70	1000	500	1000	1000	375701	0.819	11371224
8	80	1600	250	2000	500	314485	1.046	14514423
9	90	2800	250	1500	1000	303063	1.499	20808418
10	100	2800	-	4000	500	296060	1.610	22334640

Table 1

Sizing and various cost estimates for a solar-powered green microgrid operating at multiple RF frequencies

As can be observed in Table 1 the different RF each have their own unique dimensions, operational costs ($/year), LCOE ($/kWh), and TNPC values. At an RF of 10%, a diesel generator meets 90% of the load demand, while RES meet the remaining 10%. At low RF values, there is maximum diesel fuel used, and the fuel cost is maximum; consequently, there is maximum operational cost, which is equal to 754 814 dollars per year. In a similar vein, when all of the demand is satisfied by RES at 100% renewable fraction, there is a minimum operational cost of the system because there is no use of diesel generator, which is equal to 296060 dollars per year. The HRES identifies CO2, CO, NO, and SO2 as the major pollution contributors. The values of a variety of emission characteristics can be found in Table 2, which is organized according to the percentage of renewable energy used:

Table 2 Environmental Emissions in Relation to Renewable fraction for Solar-Powered Green Micro grid

S. No.	Renewable Fraction (%)	Environmental Pollutant (kg/year)			
		Carbon Dioxide Emission (CO_2)	Carbon Monoxide Emission (CO)	Sulfur Dioxide Emission (SO_2)	Nitrogen Oxides Emission (NO)
1	10	2135345	5271	4288	47032
2	20	1812799	4299	3836	42672
3	30	1591877	3929	3197	35062
4	40	1495308	3657	2999	31922
5	50	1358073	3352	2727	29912
6	60	853471	2107	1714	18798
7	70	804877	1987	1616	17728
8	80	646799	1597	1249	14246
9	90	603435	1489	1212	13291
10	100	0	0	0	0

Table 2

Diesel generators are required in a hybrid green micro grid as a result of the increased use of RES in the surrounding environment. Emissions of CO2, CO, SO2, and NO are the most significant contributors to pollution in the environment. Table 2 makes it abundantly evident that there are maximum values of all the pollutants at a renewable fraction of 10%, and if the renewable fraction is steadily increased up to 100%, these values continue to decrease in a continuous fashion. This can be seen clearly in the table. Because renewable energy sources are used, there are no environmental emissions at 100% renewable energy due to the utilization of these sources. In addition, it was discovered that carbon dioxide, or CO2, is the most dangerous pollutant and primary cause of environmental emission among all of the contaminants. Figure 2 displays the results of observations made about the behavior of the operating cost and CO2 emissions at various RF settings. When the RF values are increased from 10 to 100, there is a steady decline in the amount of CO2 emissions and operational expenses.

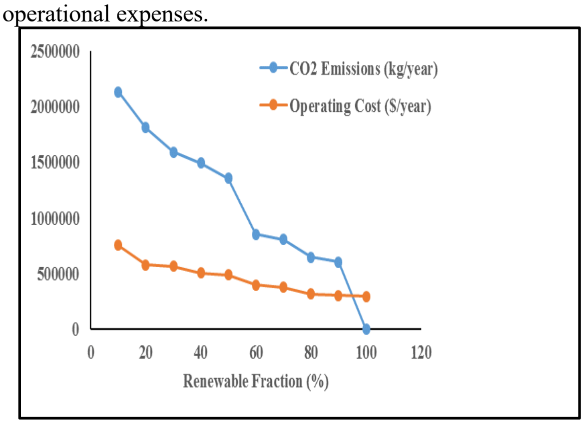

Figure 2 Patterns of CO_2 Emissions and Operating Expenses for Solar-Powered Green Micro grids at Varying Renewable fraction

Wind Green Micro grid

The second case study focuses on a wind green micro grid, which is defined as a micro grid that contains a wind turbine, DG, battery, and converter but does not contain solar photovoltaic panels. Table 3 displays the various cost parameter values as well as the techno-economic sizing of the wind green micro grid system. Table 3 Sizing of Resources in Accordance with Their Renewable Fraction for a Wind-Powered Green Micro grid

S. No.	Renewable Fraction (%)	Sizing of Renewable Energy Resources				Operating cost ($/year)	Levelized Cost of Energy ($/kWh)	Total Net Present Cost ($)
		Wind Turbine (Qty)	Diesel Generator (KW)	Battery (Qty)	Converter (KW)			
1	10	20	500	-	-	629872	0.605	8400381
2	20	40	500	-	-	613395	0.606	8409740
3	30	50	750	1000	1000	427451	0.508	7047014
4	40	100	500	-	-	382880	0.607	8423584
5	50	100	1000	2000	1000	341840	0.524	7266864
6	60	150	500	1000	1500	312637	0.482	6685049
7	70	200	250	1000	500	252508	0.451	6262145
8	80	200	250	3000	500	230761	0.532	7384144
9	90	400	250	2000	1500	224749	0.645	8947301
10	100	1200	-	9000	1500	184460	1.774	14624694

Table 3

As can be seen in Table 3, the sizes and cost values of the components in this system at the various RFs each have their own unique characteristics.

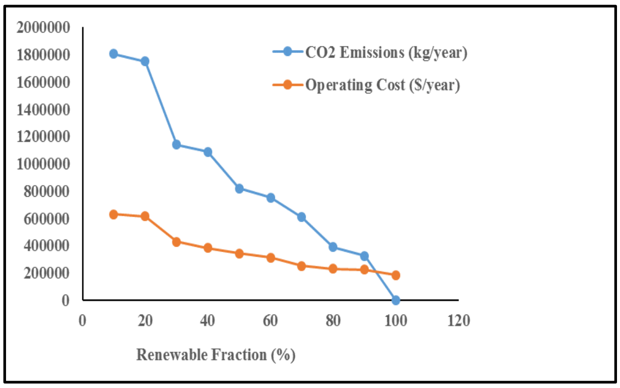

Figure 3 Operating Costs and CO_2 Emission Patterns for Wind-Powered Green Micro grids at Various fractions

Hybrid Micro grid

The third micro grid case study focuses on a hybrid green micro grid, which is defined as a micro grid that incorporates solar PV, wind turbines, hydroelectricity, distributed generation, batteries, and converters. A simulation environment is used to acquire the various cost values at other RFs. Table 5 displays the results of the cost assessment as well as the techno-economic sizing that was performed on the hybrid green micro grid system. According to Table 5, when the RF is set to 10%, the operating costs are at their highest because of the amount of diesel fuel that is consumed, which is 351,007 dollars per year. At 100% RF, the operational cost value is calculated to be 66,096 dollars per year, and as the RF values continue to climb up to 100%, the operating cost value continues to decrease. Table 6 provides the numbers for environmental emissions at each distinct RF. After the value of the Renewable Fraction (RF) in a hybrid system has increased to beyond 80%, the Total Net Present Cost (TNPC) of the system will grow dramatically. This will cause the Level zed Cost of Energy (LCOE) to also rise. It is correct to say that it is dependent on the specific RES.the TNPC and LCOE both go up when the RF value is increased to 70%. This is also true in the case of solar micro grids.

S. No.	Renewable Fraction (%)	Sizing of Renewable Energy Resources						Operating cost ($/year)	Levelized Cost of Energy ($/kWh)	Total Net Present Cost ($)
		Solar PV (KW)	Wind Turbine (Qty)	Hydro Turbine (kW)	Diesel Generator (KW)	Battery (Qty)	Converter (KW)			
1	10	100	-	-	250	500	500	351007	0.398	5531298
2	20	-	32	-	250	500	500	327652	0.362	5024748
3	30	100	32	-	250	1000	500	298144	0.400	5557525
4	40	200	32	-	250	500	500	273214	0.393	5448844
5	50	-	56	73.6	250	1500	500	247562	0.358	4967917
6	60	100	64	73.6	250	500	500	212943	0.322	4473383
7	70	400	16	73.6	250	1000	500	152618	0.375	5204217
8	80	300	64	73.6	250	1000	500	129699	0.352	4879236
9	90	1500	16	73.6	250	500	500	125855	0.769	10672097
10	100	1500	40	73.6	-	1500	500	66096	0.779	10807932

Table 4

Environmental Emissions with Regard to Renewable fraction for Green Hybrid Micro grid Systems

S. No.	Renewable Fraction (%)	Environmental Pollutant (kg/year)				
		Carbon Dioxide Emission (CO_2)	Carbon Monoxide Emission (CO)	Sulfur Dioxide Emission (SO_2)	Particulate Matter Emission (PM)	Nitrogen Oxides Emission (NO)
1	10	1010417	2494	2029	188	22255
2	20	931158	2298	1870	173	20509
3	30	803728	1984	1614	150	17702
4	40	746705	1843	1500	139	16446
5	50	605019	1493	1215	113	13326
6	60	561630	1386	1128	105	12370
7	70	351063	867	705	65.3	7732
8	80	267782	661	538	49.8	5898
9	90	263672	651	529	49.1	5807
10	100	0	0	0	0	0

Table 5

When a hybrid system relies heavily on non-renewable sources like diesel generators, the amount of environmental pollutants produced by the system is significantly increased. According to Table 6 there are maximum values of all the pollutants at a renewable fraction of 10%. This is clear from looking at the table. In the event that the proportion of renewable resources kept growing up to one hundred percent, the levels of environmental pollutants would continue to fall, and once RF reached one hundred percent, there would be no ecological emissions.

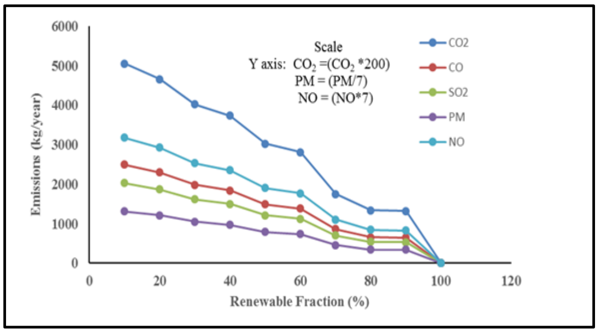

Figure 4 Emissions from the environment that are distinct in a hybrid green micro grid operating at 10% RF. behave differently depending on the proportion of renewable energy that is used. The three practical case studies came to the conclusion that the share of renewable energy sources had an inverse relationship with operating costs and CO2 emissions. The patterns for the LCOE and TNPC are not the same as the operational cost. Figure 5 and Figure 6 illustrate the level zed cost

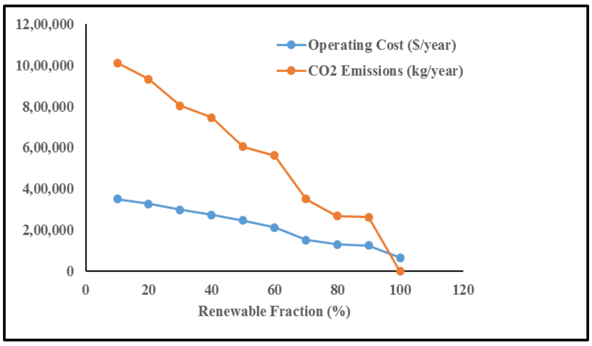

Figure 5 The Operating Cost and CO2 Emission pattern at Various R.F.s for Hybrid Green Micro grids

The values of all the environmental emissions parameters in hybrid micro grids are displayed in Figure 3. The results of this research indicate that carbon dioxide is a significant ecological emission source. Figure 4 illustrates how the operational cost and CO2 emission for hybrid micro grid systems behave differently depending on the proportion of renewable energy that is used. The three practical case studies came to the conclusion that the share of renewable energy sources had an inverse relationship with operating costs and CO2 emissions. The patterns for the LCOE and TNPC are not the same as the operational cost. Figure 5 and Figure 6 illustrate the level zed cost of energy and total networked power cost trend for a solar, wind, and hybrid green micro grid system at varying proportions of renewable energy.

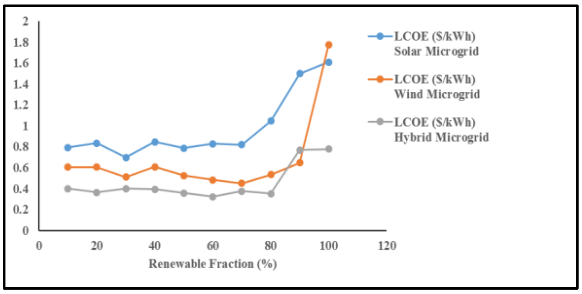

Figure 6 The Level zed Cost of Energy (LCOE) in comparison to the Renewable Fraction (RF) for three distinct scenarios The wind micro grid system follows the same trend for environmental emission parameters that is shown in the solar green micro grid system,. The operating cost and CO2 emission pattern for the wind micro grids system is displayed. As the frequency of the radio frequency (RF) increases, the average values of operating cost and CO2 emissions continue to fall.

Table 4 Environmental Emissions in Relation to Renewable fraction for Wind-Powered Green Micro grid Systems behave differently depending on the proportion of renewable energy that is used. The three practical case studies came to the conclusion that the share of renewable energy sources had an inverse relationship with operating costs and CO2 emissions. The patterns for the LCOE and TNPC are not the same as the operational cost. Figure 5 and Figure 6 illustrate the level zed cost behave differently depending on the proportion of renewable energy that is used. The three practical case studies came to the conclusion that the share of renewable energy sources had an inverse relationship with operating costs and CO2 emissions. The patterns for the LCOE and TNPC are not the same as the operational cost. Figure 5 and Figure 6 illustrate the level zed cost

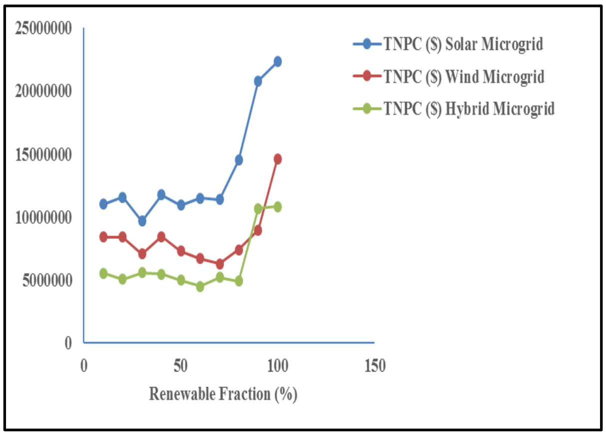

Figure 7 Comparison of the Total Net Present Cost to the Renewable Fraction (RF) for three distinct scenarios

It has been noted, and the evidence can be provided that the level zed cost of energy (LCOE) as well as the total networked power cost (TNPC) basically remain constant up to 70% RF in the case of solar green micro grids and wind green micro grids. This is something that can be seen in the case of wind green micro grids and solar green micro grids. However, when it comes to hybrid green micro grids with up to 80% RF, the LCOE and TNPC are virtually the same. Once we pass that threshold, we see a large jump in both the TNPC and the LCOE. Therefore, the optimal values for these scenarios these scenarios include solar green micro grid, wind green micro grid, and hybrid green micro grid:

Three distinct cost values for each of the three situations' respective RF values

S.No	Microgrid	Optimal RF (%)	Optimal Sizing of Renewable Energy Resources						Operating Cost ($/year)	LCOE ($/kWh)	TNPC ($)
			Solar PV (KW)	Wind Turbine (Qty)	Hydro (KW)	DG (KW)	Battery (Qty)	Converter (KW)			
1	Solar	70	1000	-	-	500	1000	1000	375701	0.819	11371224
2	Wind	70	-	200	-	250	1000	500	252508	0.451	6262145
3	Hybrid	80	400	16	73.6	250	1000	500	129699	0.352	4879236

Table 6

Conclusion

This chapter will estimate the ideal size of solar, wind, hydro, distributed generation, batteries, and converters based on operational costs, environmental emissions, level zed cost of electricity (LCOE), and total networked power consumption (TNPC). During the course of the study, it was determined that the principal source of emissions is just CO2, and that as RF grows, both operating costs and carbon emissions fall. Additionally, it was discovered that increasing RF causes a decrease in emissions of carbon. However, the LCOE and TNPC for solar green micro grids and wind green micro grids practically remain constant up to 70% RF. After that point, the cost values experience a considerable increase. After reaching 80% of RF, there is a large increase in these cost values; nevertheless, the values of this cost stay constant for hybrid green micro grids up until that point. The findings of the analysis conducted in this chapter led to the conclusion that obtaining the appropriate RF value is important in order to properly size RES.

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