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Importance of Off-Grid Power Generation using Renewable Energy Resources - A Review

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ABSTRACT
Today electricity is the basic requirement for the development of any country. In this modern world, on one hand many places are developed or developing very rapidly and on the other hand, some places are still there, where electricity is not more than a dream. In most of the cases this situation is due to the remoteness of these places from the main grid. Also the population of these places are scattered over a very large area. The extension of the grid to these individual places requires a big investment due to the low population density over these areas. The solution for this problem is that the electricity should be generated locally in these areas. Also the setup of conventional power plants is not economical at these places. In this paper, different possibilities of decentralized power generation using renewable energy are reviewed, based on the availability of renewable resources and load demand. The resources may be solar, wind, biogas, biomass, micro-hydro, individual as well as hybrid basis.

Keywords
Decentralised system, battery throughput, Integrated Renewable Energy System (IRES), Multi-Criteria Decision-Making (MCDM).

1. INTRODUCTION
In India, many areas are still un-electrified due to their remote location from main grid and low population density. The electrification of places from main grids causes major investments and losses and is the basis of decentralized generation of electricity [1]. The cost of power supply to these remote areas is at higher side. Also it is very difficult to maintain the reliability & efficiency of the system when main grid is extended to these remote areas. When the grids are extended, the power losses are also increases accordingly [2]. Now a days renewable energy sources are gradually recognized as alternative option for planning for micro grids. These microgrids are locally located nearby the area at which the power generation is taking place and the consumers are also nearby these microgrids [3]. In order to utilize renewable energy sources in the field, an Integrated Renewable Energy System (IRES) can be modelled and optimized to meet the energy needs. Different software tools are available for optimization of hybrid system of renewable energy sources [4].

In this period of time, the electrification of remote areas is also considered to increase the development of these areas as well as the country. Developing as well as developed countries are also considering the importance of power supply to these remote areas [5]. Also the use of fossil fuels is leading the world toward a unhealthy world. This problem of fossil fuels is also directing the world towards the renewable energy sources [6]. In recent times the crisis of water, coal, and other fossil fuels required by the conventional power plants is continuously increasing. Due to that renewable energy sources are being considered as alternative of these types of power sources. The decentralised power generation with renewable energy sources are helping to overcome these problems. [7].

The decentralised power generation with solar and wind energy systems is possible at most of the places. Also these energies are freely available. They are considered as promising power generation sources due to their high reliability [8]. The decentralised hybrid power generation system provides more reliability and low cost when compared to single resource power generation system. The combination of different systems to establish hybrid power generation plant, depends on the different factors (like geographic location, solar radiation, average wind speed etc.) associated with the site location [9].

Small-scale decentralized systems, where energy production and consumption are usually tightly coupled, are emerging as a viable alternative. In addition, the close connection between energy generation and consumption makes decentralized systems cleaner because they are most often based on renewable energies or on high-efficiency fossil fuel-based technologies. These decentralized power systems can have hybrid system of wind power, solar PV cells, micro hydro turbine, biogas or diesel generator, depending on the resource availability at a particular location [10].

2. LITERATURE REVIEW
Santosh Rana et al. have studied the potential of various renewable resources in villages of Madhya Pradesh (India). The villages were categorized into five categories on the basis of the combination of available resources and technology, capable of meeting their demand at the lowest cost. The demand of villages of category (1) was met by biogas-based technology only. The per unit electricity cost (PUEC) of these villages lies between Rs. 4.1 and Rs. 5.7/kWh. For villages of category (2), where demand was met by a combination of biogas and biomass technologies, the PUEC lies in the range Rs. 4.1 to Rs. 5.8/kWh. The PUEC of villages of category (3), where demand was met by biomass-based technology only, lies in the range Rs. 4.7 to Rs. 8.2/kWh. The PUEC of villages where demand was met by a combination of biogas, biomass-based power generation and PV technology, varies between Rs. 4.7 and Rs. 18.0/kWh (category 4). Category (5) includes those villages that do not have an appreciable amount of biomass or dung, and hence their demand was solely met by Photo Voltaic (PV) systems. The PUEC of these villages varies between Rs. 16.1 and Rs. 21.3/kWh. It is found that

villages that have good biogas potential correspond to the lowest PUEC [1].

A.K. Akella et al. selected Jaunpur block of Uttaranchal state of India as remote area for sudy and estimated that the total load was 808 MWh/yr and total available resources were 807 MWh/yr, whereas percentage contribution of each resources were, MHP 15.88% (128166kWh), solar 2.77% (22363kWh), wind 1.89% (15251kWh) and biomass energy 79.46% (641384kWh). The model has optimized using LINDO software 6.10 version. Renewable energy sources can contribute to the total energy demands as 16.81% (115465kWh), solar 2.27% (15588kWh), wind 1.78% (12201kWh) and biomass energy 79.14% (543546kWh) for the fulfilment of 687 MWh/yr at the 15% reduced level of 808 MWh/yr load. The results indicated that optimized Integrated Renewable Energy Sources (IRES) can provide a feasible solution in terms of energy fulfilments in the range of Electric Power Delivery Factor (EPDF) from 1.0 to 0.75 because below 0.75 EPDF (0.50–0.25) the deficit starts and so that model becomes non-feasible solution [4].

Due to multiple generation systems, hybrid system analysis is quite complex and requires to be analyzed thoroughly which requires software tools for the design, analysis, optimization, and economic viability of the systems. It is always desired to minimise the PUEC & increase the utilization of available resources. These software tools like HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, and SOMES are used to design the hybrid power system to fulfil the energy demand and at the same time maintaining the lowest PUEC. The various types of analysis by these softwares are shown in the table 1 [11].

Table 1. Main highlights of various software tools for hybrid systems

Sr. No.	Software Name	Latest Version	Analysis Type
1	HOMER	HOMER Pro Version 3.11.2	Technical Analysis Economical Analysis Emission Analysis
2	HYBRID2	Version 1.3	Technical Analysis Economical Analysis
3	RETScreen	RETScreen 4	Economical Analysis Environmental Analysis
4	iHOGA	Version 2.2	Multi or mono objective optimization using genetic algorithm
5	INSEL	INSEL 8.2	Planning, monitoring of electrical and thermal energy systems
6	TRNSYS	Version 17.1	Simulate transient system behavior
7	iGRHYSO	-	Technical Analysis Economical Analysis
8	HYBRIDS	-	Technical analysis
9	RAPSIM	Version 2	Simulates performance of a range of hybrid power systems
10	SOMES	-	Technical Analysis Economical Analysis

S. Ashok reviewed Western Ghats (Kerala), for the case study to find the suitable component sizes and optimal operation strategy for an integrated energy system. The village has 120 families with a population of over 600. The optimal operation shows a unit cost of Rs. 6.5/kWh with the selected hybrid energy system (PV-wind system) with 100% renewable energy contribution eliminating the need for conventional diesel generator. The criterion of selecting the best hybrid energy system combination for a proposed site is based on the trade-off between reliability, cost and minimum use of diesel generator sets. Locally available standard micro-hydro, wind and solar PV units suitable to the resource measurements are selected for unit sizing for the benefit of service and maintenance. 15kW, 3 Phase Kaplan-Induction-type micro-hydro turbo units, 5kW 3 Phase AEP 5000 asynchronous wind units, 120WBP Solar 33 V, 3.56A PV units, 5 kW 3 Phase DG sets and 360AH, 6V battery units are used for calculation. The micro-hydro contributes 78% and wind 22% of the total supplied energy system. The battery throughput was 85 kWh/day. The unit cost of electricity for the above hybrid system is Rs. 6.5/kWh. A 25kVA diesel generator is required to supply the whole population with unit costs of Rs. 11.63/kWh. This hybrid system with battery backup will provide 24-hour electric supply to every household in the village. The total renewable energy fraction of electricity is 100%, which eliminates the need for conventional diesel generator [12].

O. Erdinc and M. Uzunoglu reviewed the concept of an optimum sizing approaches that can make significant contributions to wider renewable energy penetration by enhancing the system applicability in terms of economy and meet the demand [13].

In order to verify feasibility and cost of system for different biomass fuel prices, a sensitivity analysis carried out by A.B. Kanase-Patil et al. used four different renewable energy scenarios. The IRES system accounted 44.99% micro hydropower (MHP), 30.07% biomass, 5.19% biogas and 4.16% solar energy along with the additional resources of wind (1.27%) and energy plantation (12.33%) found to be the best among the different options considered. Furthermore, the optimal reliability for the fourth IRES system found to be 0.95 Energy Index Ratio (EIR) at the optimized cost of Rs 19.44 lacs with estimated COE of Rs 3.36 per kWh. The COE obtained using LINGO software and HOMER software also compared and briefly discussed for all the four scenarios[14].

G.J. Dalton et al. have analysed stand-alone renewable energy supply options for a remotely located large hotel in Australia. The assessment criteria of the analysis were net present cost, renewable factor and payback time. This study used RES assessment software tools, HOMER (National Renewable Energy Laboratory, US) and HYBRIDS (Solaris Homes, Queensland, Australia), in order to compare diesel generator-only, RES-only and RES/diesel hybrid technologies. HOMER uses hourly load data, whilst HYBRIDS uses average daily energy demand for each month. Optimisation modelling demonstrates that 100% of power demand can be supplied by a RES-only configuration. A hybrid diesel/RES configuration provides the lowest NPC result with a resultant RF of 76%. In comparison to the diesel generator-only configuration, NPC is reduced by 50% and Greenhouse Gas (GHG) emissions by 65%. The payback time of the hybrid RES scenario is 4.3 years. Results indicate that wind energy conversion systems (WECS), rather than photovoltaics, are the most economically viable RES for large-scale operations. Large-scale WECS (over 1000kW) are more efficient and economical than multiple small-scale WECS (0.1–100 kW). Both modeling tools produced similar results, with HYBRIDS producing on average slightly higher NPC results than HOMER. The modeling and resulting data from the analysis indicate that RES is technically feasible and economically viable as a replacement for conventional thermal energy supply for large-scale tourist operations dependent on stand-alone power supplies [15].

K.Y. Lau et al. done the performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions. HOMER software was used to perform the techno-economic feasibility of hybrid PV/diesel energy system. The investigation demonstrated the impact of PV penetration and battery storage on energy production, cost of energy and number of savings and reduction in carbon emissions of different hybrid systems. A remote area of 40 houses was taken for the performance analysis. Each house required loads of 2 kW peak. Therefore, 40 houses would require a maximum of 80 kW peak demand, approximately. The energy demand required by the remote inhabitant area, as simulated by HOMER software, was estimated to be about 1156 kWh/day (or 421.94 MWh/year). When the use of hybrid PV/diesel system with battery (one unit of 60 kW PV array, two units of 50kW diesel generator, with 12 units of battery) was considered, it was found that operating cost of the system has been reduced to $ 89,170 per year. This was the cheapest among the different configurations proposed. This is a huge reduction as compared to the standalone diesel system [16].

Alam Hossain Mondal et al. selected remote areas of Bangladesh. The main objective of the study was to determine the optimum size of systems able to fulfill the requirements of 50 kWh/day primary load with 11 kW peak load for 50 households for three remote sites located at Cox's Bazar, Sylhet and Dinajpur. The methodology applied provides a useful and simple approach for sizing and analyzing the hybrid systems using HOMER. The analysis results show that PV (6 kW)–diesel generator (10 kW)–battery hybrid system is most economically feasible and least cost of energy is about 25.4 Tk/kWh(1USD=68.5 Taka). The result also indicates that the decrease in CO2 emissions by using the feasible hybrid system with 40% renewable fraction is about 38% as compared to the diesel-only system [17].

Rohit Sen et al. selected the remote village Palari in the state of Chhattisgarh, India for the analysis of optimised hybrid renewable power generation system using HOMER. They considered solar, wind, micro-hydro and bio-diesel resources in this simulation. The optimal combination of RET system components for their case study was a 20 kWPV-array, 30kWSHP,10 kWBDG, 40 Surrette 6CS25P batteries, 20 kW inverter and a 20 kW rectifier with a dispatch strategy of cycle charging. The COE of $0.420/kWh from this hybrid system is cheaper than that of $0.44/kWh from grid extension as considered for this study [18].

Sanjoy Kumar Nandi et al. selected remote areas of Chittagong, Bangladesh to analyses wind-PV–battery hybrid power system as an alternative to grid extension in the mentioned area. Analysis of hybrid system showed that for 53,317 kWh/year load the cost of energy was 0.47USD/kWh with 10% shortage of capacity and was producing 89,151 kWh/year in which 53% electricity was from wind and the remaining energy from solar power. This hybrid system will reduce about 25t CO_2/yr and greenhouse gases (GHG) emission in the atmosphere [19].

Arash Asrari et al. studied the Binalood region in Iran. Binalood region have an average wind speed of 6.82 m/s at 40 m elevation and also an average daily solar radiation of 4.79 kWh/m2/day. It is possible to have a stand-alone hybrid renewable energy system in a remote rural village in Binalood region, called Sheikh Abolhassan, which can satisfy load demand of this region. In this region, authors have compared the different available sources & the per unit electricity cost (PUEC) of the power supply with hybrid power generation plant. Firstly, the power was generated by diesel generator & then renewable energy sources were used. And it is found that the cost of energy was reduced. On a second stage, author discussed how renewable energy sources (RESs) can still be added to the current utility grid power supply in Sheikh Abolhassan to achieve a more economical and environmentally friendly system. PV–wind–diesel–battery design, which consists of one 5 kW PV array, one BWC Excel-S wind turbine, one 15 kW diesel genera- tor, 10 batteries and a 10kW power converter, with a total NPC of $202,905 and a COE of $0.422/kWh. As can be observed, such a system results in a renewable fraction (RF) of 45% [20].

Shubha Singh and A.K. Kori discussed the models of distribution system with considerable distributed power generation to improve the power quality and voltage stability and also present a outline for estimating auxiliary service from the generator, this provides an improved plan and better services for the emerging countries to get their structure to meet discrete load while optimizing for renewable and extra decentralized source [21].

Espen Loken emphasize on the importance of Multi-Criteria Decision Making (MCDM) to get the best configuration of possible hybrid system which satisfies the different aspects like energy demand, economic condition of area, social impact etc. The paper endorses a hybrid approach that combines two or more choices to take benefits of strengths and weaknesses of different choices [22].

3. CONCLUSION

In this paper different alternative methodologies have reviewed that have been reported in the literature. The reviewed material included academic literature on case studies, specific tools such as optimization tools, Multi-Criteria Decision-Making tools and practice-based literature. Based on this review:

- It was found that most of the literature has focused on techno-economic dimensions and environmental aspects of the problem, with design of technical system and economic feasibility with available resources.
- Only the Multi-Criteria Decision-Making (MCDM) approach appears to consider the economic, social and environmental aspects but this approach is inadequate to develop the system and analyses the detailed feasibility of the system. The participatory, whole systems approach on the other provides a feasible alternative but will require more efficacies for capacity development.

- The past literature on the other hand has considered the pertinent factors but has not necessarily focused on an integrated analytical framework.

The paper advocates a hybrid tool that can be used in varying case study situations. The hybrid option allows for the verification of results from alternative approaches and can accessory the strengths and shortcomings of each approach. However, this can be resource intensive and therefore will require a careful consideration on a case-by-case basis.

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