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Hybrid Renewable Energy Systems: A Review

Pankaj Agarwal[1]

[1]Assistant Professor, Amity University Rajasthan

Abstract: Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.The wind and solar energy are omnipresent, freely available, and environmental friendly. The wind energy systems may not be technically viable at all sites because of low wind speeds and being moreunpredictable than solar energy. The combined utilization of these renewable energy sources are therefore becoming increasingly attractive. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. These hybrid energy systems are becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products. Research and development efforts in solar, wind, and other renewable energy technologies are required to continue for, improving their performance, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating sources. The aim of this paper is to review the current state of the design, operation and control requirement of the stand-alone PV solar–wind hybrid energy systems with conventional backup source i.e. diesel or grid. This Paper also highlights the future developments, which have the potential to increase the economic attractiveness of such systems and their acceptance by the user

I. INTRODUCTION

Hybrid renewable energy systems (HRES) are becoming popular for remote area power generation applications due to advances in renewable energy technologies and subsequent rise in prices of petroleum products. A hybrid energy system usually consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply. One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas, where the grid extensions costly and the cost of fuel increasesdrastically with the remoteness of the location. Recent research and development in Renewable energy sources have shown excellentpotential, as a form of supplementary contribution to conventional power generation systems. Renewable energy sources, such as photovoltaic,wind energy, or small scale hydro,provide a realisticalternative to engine-driven generators for electricity generation inremote areas. It has been demonstrated that hybrid energysystems can significantly reduce the total lifecycle cost of standalonepower supplies in many situations, while at the same timeproviding a more reliable supply of electricity through the combination of energy sources.

Various hybrid energy systems have been installed inmany countries over the last decade, resulting in the development ofsystems that can competewith conventional, fuel based remote area power supplies in many applications. In India, it is difficult to electrify the remote areas of Kumoan region and the odd small villages in TehriGarwal district. It is uneconomical to provide grid power in these areas so hybrid renewable energy systems are very useful to electrify these remote villages. Various simulation programs are available,which allow the optimum sizing of hybrid energy systems.The recent state of art hybrid energy system technologicaldevelopment is the result of activities in a number of researchareas, such as

A. Advances in electrical power conversion through the availabilityof new power electronic semiconductor devices, have led toimproved efficiency, system quality and reliability.

B. Development of versatile hybrid energy system simulationsoftware; continuing advances in the manufacturing processand improve efficiency of photovoltaic modules.

C. The development of customized, automatic controllers, whichimprove the operation of hybrid energy systems and reducemaintenance requirements.

D. Development of improved, deep-cycle, lead-acid batteries forrenewable energy systems.

E. Availability of more efficient and reliable AC and DC appliances,which can recover their additional cost over their extendedoperating lifetime.

F. The task for the hybrid energy system controller is to control theinteraction of various system components and control

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powerflow within the system to provide a stable and reliable source of energy.

With the wide spread introduction of net-metering, the use of smallisolated or grid connected hybrid energy systems is expected to growtremendously in the near future. The aim of this paper is to review thecurrent state of the design and operation of hybrid energy systems, and to present future developments, which will allow a furtherexpansion of markets, both in industrialized and developingcountries.

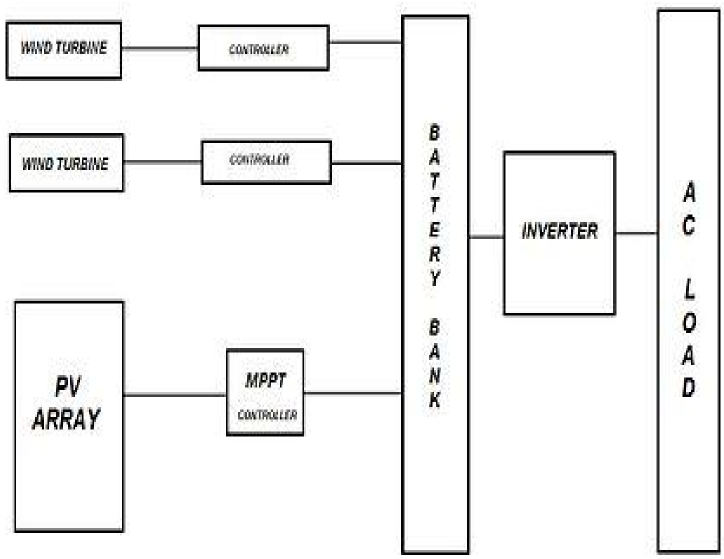

Fig.1. Block diagram of a PV/wind hybrid energy system

II. PRE-FEASIBILITY ANALYSIS OF HYBRID SYSTEM

Climatic conditions determine the availability and magnitudeof wind and solar energy at particular site. Pre-feasibility studiesare based on weather data [3] (wind speed, solar insolation) andload requirements for specific site. In order to calculate theperformance of an existing system, or to predict energyconsumption or energy generated from a system in the designstage, appropriate weather data is required. The global whetherdata could be obtained from internet and other sources likelocal metrological station. The global weather pattern is taken fromNASA surface metrological station shown in Figs. 2 and 3. In Fig. 2the red and yellow indicate high wind energy is available while theblue colors reflect lower wind energy potential zone. Fig. 3 shows the solar insolation level at different areas of the world. Wind and solar hybrid system can be designed with the help of these global weather patterns, for any location all over the world. Feasibility of hybrid PV/wind energy system strongly depends on solar radiation and wind energy potential available at the site. Various feasibility [38] and performance studies are reported to evaluate option of hybrid PV/wind energy systems [22, 50].

Photovoltaic array area, number of wind machines, and battery storage capacity play an importantrole in operation of hybrid PV/wind–diesel system while satisfyingload [1]. The objective of lightingpathway at the project site can be achieved by making use of thewind, solar and hydro energy

sources. The information about localwind, a solar and hydro energy source indicates that a feasiblehybrid energy system can be planned, modeled and designed forthe above purpose. The collected data of the various energy sourceswas analyzed in order to plan for the structure of the system. This model also allows anoptimal capacity of the hybrid energy system to be determined. Khan and Iqbal [22] discussed a primary design and pre-feasibilityanalysis of a hybrid energy system for a household in or around St.John's, Newfoundland. He collected 1-year wind speed, solarradiation and power consumption data of a house in St. John's, New found land which was used for the feasibility study of a hybridenergy system.

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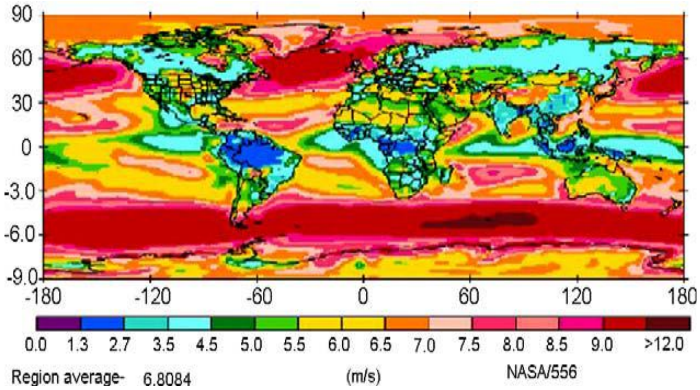

Fig.2. Global wind energy potential [75].

Wind power is one of the most efficient alternative energy sources. India is having a net potential of about 45000 MW only from 13 identified states. Wind resources can be exploited mainly in areas where wind power density is at least 400 W/m2 at 30 m above the ground. An annual mean wind power density greater than 200 W/m2 (watts per square meter) at 50-m height has been recorded at 211 wind monitoring stations, covering 13 states and union territories. India's wind power potential has been assessed at 45,000 MW. Acapacity of 15700MW has been installed. Solar power has so far played an almost non-existent role in the Indian energy mix. The grid-connected capacity in the country now stands at 481.48 MW, while the total solar energy potential has been estimated at 50,000 MW. Most parts of India have 300 – 330 sunny days in a year, which is equivalent to over 5000 trillion kWh per year. Average solar incidence stands at a robust 4 – 7 kWh/sqmtr/day.

States /UTs	Estimated potential (MW)	
	@ 50 m ($)	@ 80 m (* #$)
Andaman & Nicobar	2	365
Andhra Pradesh	5394	14497
Arunachal Pradesh*	201	236
Assam*	53	112
Bihar	-	144
Chhattisgarh*	23	314
Dieu Damn	-	4
Gujarat	10609	35071
Haryana	-	93
Himachal Pradesh *	20	64
Jharkhand	-	91
Jammu & Kashmir *	5311	5685
Karnataka	8591	13593
Kerala	790	837
Lakshadweep	16	16
Madhya Pradesh	920	2931
Maharashtra	5439	5961
Manipur*	7	56

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Meghalaya *	44	82
Nagaland *	3	16
Orissa	910	1384
Pondicherry	-	120
Rajasthan	5005	5050
Sikkim *	98	98
Tamil Nadu	5374	14152
Uttarakhand *	161	534
Uttar Pradesh *	137	1260
West Bengal*	22	22
Total	49130	102788

Table 1. Estimation of installable wind power potential at 80 m level

Wind potential has yet to be validated with actual measurements.
Estimation is based on meso scale modeling (Indian Wind Atlas).
As actual land assessment is not done on a conservative consideration 2 % land availability for all states except Himalayan & North eastern states, Andaman Nicobar Islands and Poor windy states has been assumed. In other area 0.5% land availability has been assumed.

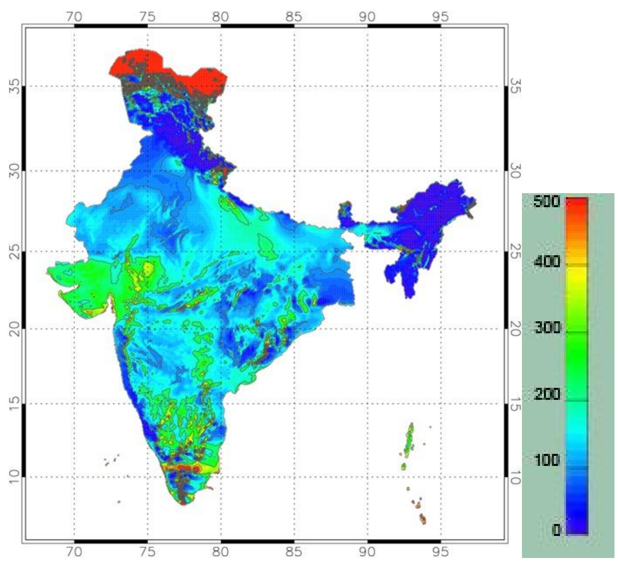

Fig3. Wind power density map at 80 m level[76]

III. UNIT SIZING AND OPTIMIZATION

After pre-feasibility study the selection of proper sizing ofequipment is made based on weather data and maximum capacity.The unit sizing of integrated power system plays an important rolein deciding the reliability and economy of the system. In thissection, study by the different researchers discussing differentmethods to determining the wind generator capacity and thenumber of PV panels and other sources and number of batteryneeded for the stand-alone system is reviewed. Using the measured data of solar and wind energy at agiven location, author employ a simple graphical construction todetermine the optimum configuration of the two generators thatsatisfies the energy demand of the user throughout the year. Kattiand Khedkar [9] develop the algorithm uses hourly average windspeed, insolation, and power demand to determine the wind/PVgeneration capacities required to meet the demand without loss ofpower supply probability (LPSP). Elhadidy and Shaahid [24–26]calculated optimum battery storage size for hybrid wind energysystem by studying an impact of variation of battery storagecapacity on hybrid power generation. Tradeoff between size

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of the storage capacity and diesel power required for the load, assuming aconstant wind power output, was also reported by the authors. In2006, Koutroulis et al. [19] presented a methodology for optimalsizing [31] of stand-alone PV/WG systems using genetic algorithms.They applied design approach of a power generationsystem, which supplies a residential household.Optimum size of hybrid PV/wind energy system can becalculated on an hourly basis [17] or on the basis of daily averagepower per month, the day of minimum PV power per month, andthe day of minimum wind power per month. Performance ofhybrid PV/wind energy system was compared on hourly basis; byfixing the capacity of wind generators, yearly loss of loadprobability (LOLP) with different capacity of PV array and batterybank were calculated. Trade off curve between the battery bank and PV array capacity for given LOLP helps to find optimum configuration at least cost. They employs a linear programming techniques [34] to minimize the average production cost ofelectricity while meeting the load requirements in a reliablemanner, and takes environmental factors into consideration bothin the design and operation phases.

Yang [8] developed a novel optimization sizing model forhybrid solar–wind power generation system. To optimize thecapacity sizes [29] of different components of hybrid solar–windpower generation systems employing a battery bank, the authorsalso calculated battery size requirements to achieve desired levelof autonomy by using system performance simulation model. Itis observed that for achieving high autonomy, a backupgenerator is required and in turn reduces battery storagecapacity. Hancock et al. [61] discussed the approach to optimizehybrid PV/wind/battery system with conventional power plantand calculated optimal system configuration on the basis of Lifecycle cost.

National Renewable Energy Laboratory (NREL)'s,Hybrid Optimization Model for Electric Renewable (HOMERversion 2.19) [73] has been used as the sizing and optimizationsoftware tool [72]. It contains a number of energy componentmodels and evaluates suitable technology options based on costand availability of resources. Analysis with HOMER requires information on resources, economic constraints, and controlmethods. It also requires inputs on component types, theirnumbers, costs, efficiency, longevity, etc. Sensitivity analysiscould be done with variables having a range of values instead of a specific number.

IV. MODELING OF HYBRID RENEWABLE ENERGY SYSTEM (HRES) COMPONENTS

Literature review reveals that over the last decades, HRES applications are growing rapidly and HRES technology has provenits competitiveness for remote area applications. It is observed that approximately 90% of studies reported are on design/economic aspects of HRES. However, fewer studies were reported on control of HRES. Utility interactive HRES [68] has yet not gained the popularity. It is expected that within the next few years HRES becomes competitive with utility grid power for wide spread distributed applications. Hence, there is a need to investigate potential and performance of PV and wind energy system to calculate level of penetration in existing networks of developed or developing countries in order to improve quality of power supply.The simulation results prove the operating principle, feasibilityand reliability of this proposed system. Solar/diesel/battery hybrid power systems [23,67] have been modeled for the electrification oftypical rural households and schools in remote areas.

V. FUTURE TRENDS FOR DESIGN AND OPERATION OF HYBRID ENERGY SYSTEM

This system can be considered for sustainable hybrid energy system, designed on two modes. One is standalone and other is grid-assisted mode. In stand-alone mode, it draws power from the wind–solar hybrid energy system. In the grid-assisted mode, when the hybrid system is unable to feed the power, it automatically takes the grid power. If the site-specific data is not available, one may use nearest meteorological station data in designing the system. The system voltage variation, the frequency, waveform and power factor at the time of grid connection, must be maintained within the limits. One can improve the power quality depending upon the local conditions. Hybrid energy flow is controlled using power electronic converters. This energy would be useful in many applications such as ship power systems, electric hybrid vehicles, telecommunication industries, rural electrification etc.

Further R&D improvements in solar PV and wind technologies will reduce the cost of renewable energy sources. The cost of conventional energy resources is increasing every year. This system is going to be economical in future. Besides the cost, the environmental benefits are likely to facilitate the widespread use and acceptance of these systems

VI. CONCLUSIONS

The hybrid energy systems are recognized as a viable alternative to grid supply or conventional, fuel-based, remote area power supplies all over the world. The review reveals that, renewable energy based low emission hybrid systems are not cost competitive

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against conventional fossil fuel power systems. However, the need for cleaner power and improvements in alternative energy technologies bear good potential for widespread use of such systems. Moreover, the rural households in industrialized and less developed countries attach high value to be liable, limited supply of electricity. Community facilities such asrural hospitals, schools, telecommunication and water pumpingstations can contribute significantly to the welfare of people andrural development. While it is recognized that technology can only be one aspect of community development, the renewable energysystems have demonstrated the potential to provide support insome of the basic infrastructure needs in remote and urban areas for different application. Although the cost reduction and technological development of hybrid energy systems in recent years has been encouraging, stillthey remain an expensive source of power. To allow the widespread application of this emerging technology, there is a need forfurther R&D improvement in solar PV and wind technologies thatcan reduce the cost of hybrid system. The cost of conventional energy resources is increasing every year, but the receding trend inthe cost of renewable energy technologies because of its widespreaduse is encouraging factor, projecting RES system an economical means of power generation in future for many standalone applications.

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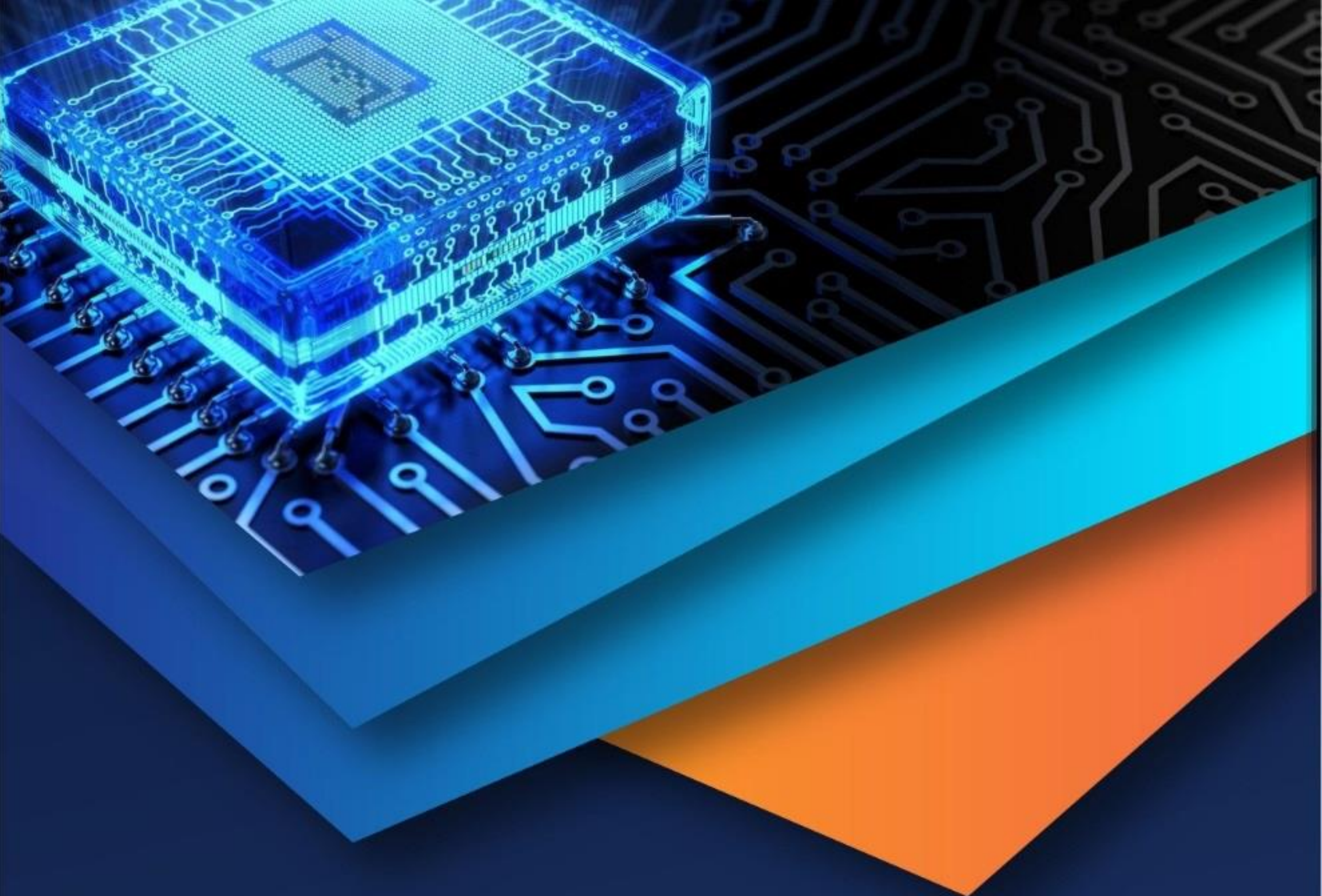

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