Hybrid Renewable Energy Systems: A Review

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***Abstract*— The global energy demand is ever increasing with the population growth but the available limited non - renewable fossil fuel resources cannot meet the demands for a longer duration. This lead to design and construct devices for supplying renewable energy which actually began some hundred years before but a serious thought was started since the 'energy crisis ' in 1970s[1].Renewable energy is energy that is inexhaustible and can be continuously replenished like solar, wind, tides, geo- thermal and various forms of biomass. These energies are available in abundance, can be constantly renewed, mostly cost free and environment friendly. But the availability of these energies occur at different times of the day and year and so hybridization of different energy systems will ensure dependability and reliability of these sources to supply power whenever we need . A combination of two or more renewable energy sources is more effective than a single source system in terms of cost, efficiency and reliability. This is called as hybrid renewable energy system (HRES) and is becoming a fast developing market world wide. This paper will be focusing on review of hybrid solar PV/wind energy systems. A review of various aspects-integration, design and optimization, control systems, energy management reliability , storage and environmental impacts of HRES will be covered.**

Keywords- Hybrid Renewable Energy systems(HRES)

Modeling, Economics, Energy Storage.

Introduction

Energy is the most important factor for both industrial and agricultural development and thus overall economic development of any country. It is obvious that the known resources of fossil fuels in the world are fast depleting. The importance of renewable energy sources was recognized in the early 18th century. Since then, a significant effort has gone into the development, trial and induction of a variety of renewable energy technologies for the use in different sectors [1] The renewable energy technology usage to meet energy demands has been steadily increasing in the past few years. However, the standalone renewable energy systems are not reliable because of intermittent availability and they are lean in nature. In the recent past, renewable energy systems like standalone solar photovoltaic, wind systems have been promoted around the globe on a comparatively larger scale. These independent systems cannot provide continuous source of energy, as they are seasonal in nature; photovoltaic energy system cannot provide reliable power during non-sunny days, the standalone wind system cannot satisfy constant load demands due to significant fluctuations in the magnitude of wind speeds from hour to hour throughout the year. Obviously a combination of two or more energy sources is more effective than a single source system in terms of cost, efficiency and reliability [4]. There are many renewable energy sources but wind & solar energy is most prominent because wind- they are well known source of energy and widely distributed everywhere. Single source of energy such as wind & PV is not totally reliable due to climate change or sunshine in night hours or rainy season and wind speed variation[3]. Knowing the importance of these forms of renewable energy, India has set the ambitious target of achieving the capacity of 175 Giga – Watts (GW) from renewable sources of energy by the year 2022, including 100 GW from solar energy and 60 GW from wind energy. Research studies have concluded that solar energy and wind energy are complementary to each other and as a result, hybridization of solar and wind technologies would reduce variable costs, optimally utilize infrastructure and land since there are several areas with moderately to high potential for both solar and wind energy. The Ministry of New and Renewable Energy (MNRE) of the Government promote large grid connected wind – solar photo – voltaic (PV) system for optimal and efficient utilization of both infrastructure and land and thereby reduce variable costs and ensure better grid stability. In this regard, the MNRE has proposed a draft National Wind – Solar Hybrid Policy, 2016 (Draft Policy) with the goal of reaching the target of wind –

solar hybrid energy of capacity 10 GW by the year 2022[3].Keeping the importance of HRES in mind, this paper reviews developments on the design, modeling, simulation, controls, economics and storage of hybrid solar PV-wind systems in the last about 10 years period.

I. DESSIGN, MODELLING AND OPTIMISATION OF HYBRID SOLAR/PV SYSTEMS

Various authors contributed for in depth research studies in this area discussed as under:

Nema etal. [6] studied PV–solar and wind hybrid energy system for GSM/CDM mobile base station in Bhopal – Central India. HOMER software was used to model the hybrid energy system. Sureshkumar et al. [7] presented real time optimal cost analysis of hybrid system based on the load profile, solar radiation and wind speed for a location Mandapam in TamilNadu,India. Liqun L,Chunxia L[9] performed feasibility ,GHC analysis of an off grid system in China using RETSCREEN software . Dufo-López et al [10] studied PV–wind –diesel hybrid system with battery storage in Spain using HOGA software . The focus of this study was on optimization of hybrid energy solar PV-wind systems and life cycle emissions. Modeling, computer simulation and optimization of hybrid power generation system in the rural area in Muqdadiyah district of Diyala state, Iraq by simulation using HOMER software and found feasible as the amount of energy generated was reasonable [12].A study on Feasibility of Solar-Wind Based Standalone Hybrid System for application in Ethiopia was carried out and found that independent wind farm was not found to be feasible but hybrid energy system using solar-wind may be feasible. HOMER software was used for the studies and simulation[13].A newly developed software was used to Study the optimum size of each component and loss of load possibility of hybrid energy system in 10 different locations at Saudi Arabia and the results out put of this software was compared with standard software like HOMER and RETSCREEN [14].Several simulation tools are readily available today in order to model, size and optimize the hybrid system. An overview of such simulation and/or optimization tools is discussed in detail by Nortan and others[15,16].Behavior of different sizes of Solar-wind hybrid systems were studied and Economic sizing for a stand alone system was found by selecting 4 different locations in Iran and the results were discussed by Ramin Hosseinalizadeh and others. The focus was on economic sizing and variations from location to location as the input parameters vary[17] A Hybrid system of Solar and Wind is simulated using MATLAB-SIMULINK by Umesh Dhakad et al. and results show the performance is better in hybrid compared to standalone solar or wind system[18]. Umesh Dhakad , Virendra Sharma developed amathematical modeling of wind-PV hybrid system for a remote village in Rajasthan , India was developed using MATLAB . The difficult and non approachable areas which are hilly and desert were selected for data collection[19].A grid connected hybrid wind-solar photovoltaic (PV) system with Maximum Power Point Tracking (MPPT) was modeled and analysed by Harini ,Ramaprabha [20].Modeling, simulation and Control of a grid connected PV and Wind Hybrid Power System with MPPT was analysed by Sunil Patel and others. It is observed that the extraction of the maximum power from SPV array is obtained using MPPT system[21].A prototype model of hybrid energy system using solar and wind energy sources for the control of street lighting in India was done and tested for optimum output. This has the scope for real time implementation as found by Mohammad Shariz Ansari et al[22].

Most researchers used MATLAB/HOMER/RETSCREEN for their modeling and analysis.

II. CONTROLS AND POWER MANAGEMENT SYSTEMS

Ahmed Chaib and others studied voltage compatibility of coupling of solar PV and wind energies into main DC bus of a hybrid system and suitable adaptor switches were suggested. MATLAB/SIMULINK modeling of the system was done to model and simulate [23].A study on change in load, change in solar irradiance level and wind speed and the related disturbances in the system performance was carried out by Rajesh Kumar and others. A PI controller based control scheme is implemented for this purpose and an MPPT is used for wind turbine to extract the maximum power from the wind resource. The validity of the control scheme is checked through the MATLAB simulation of the solar-wind based power system [24]. A control strategy for power flow management of a grid connected hybrid photovoltaic (PV) wind battery based system with MPPT with fuzzy was modeled which ensured supply of uninterrupted power to ac loads, and the evacuation of surplus PV and wind power into the gridas suggested by Ramya and DevaBrinda[25].A supervisory model predictive control method was developed by Wei Qi and others for the optimal management and operation of hybrid standalone wind-solar energy generation systems. The supervisory control system was designed via model predictive control which computes the power references for the wind and solar subsystems at each sampling time while minimizing a suitable cost function [26].The performance analysis of Grid Connected Hybrid Wind/PV System was studied by Chirag Goyani et al. Modeling, simulation and Control of a grid connected PV and Wind Hybrid Power System is simulated in Matlab/Simulink environment. It is observed that the maximum power from PV array it extracted using MPPT system [27].A hybrid Solar PV-Wind energy system for applications in isolated area in India was studied by B. Kanagasakthivel and others. The modeling and simulation of hybrid system along with the PI controllers are done using MATLAB/SIMULINK. The performance of the hybrid system is evaluated under different wind speeds and different irradiation levels

Simulation results show that the proposed hybrid system has the potential to meet the electricity demand of an isolated area [28].The design aspect of a PV and wind power input to a DC-DC converter which can be practically useful in hybrid renewable energy power systems was studied and reported by Himanshu Sharma and others . This paper covered the design of a DC-DC converter for a PV /wind hybrid system was covered and dynamic performance analysis of designed controller at different situations was studied including variations of ambient conditions at renewable energy sources [29].

III. HYBRID ENERGY STORAGE SYSTEMS

A comprehensive review of all available energy storage systems applicable to electrical power systems as discussed by various researchers is reviewed in this part of the paper. The different energy storage systems like pumped hydro, thermal, Compressed air energy storage (CAES), Fuel Cells (FC) etc., were studied in terms of their characteristics, comparison of various systems in terms of reliability, economics by H. Ibrahima et al. The various systems were compared in terms of economics and reliability[30].The role of the battery-super capacitor hybrid system as the relatively mature hybrid energy storage technique was discussed by Peng Yu and others in their research work [31].The Energy Storage Systems (ESS) is considered as an effective solution to handle the reliability and stability challenges of future power systems with large scale wind power integration. Various storage systems like Flywheel Energy Storage (FES), Battery Energy Storage System (BESS), Superconducting Magnetic Energy Storage (SMES) are discussed including size, type and site selection besides operation and controls by Haoran Zhao et al. [32] Emerging methods of ESS were covered by Bahadır Önen and others in their research , such as PHES, CAES, Batteries, HES and FES, were discussed by working principles and characteristic features in order to overcome the problems that occurs due to the intermittent and variable nature of Wind Power Plants (WPP) integration on the grid [33]. Akinyele et al. highlighted the technological progress, performance and capital costs assessment of the systems and directions for further research. Some new storage systems such as: adiabatic-, underwater/ocean-, isothermal- and small-scale CAES systems, sub-surface, seawater and variable-speed PHS systems, and pumped heat electrical storage has also been discussed[34].The role of Superconducting magnetic energy storage (SMES) ,as an excellent high-efficient energy storage device,in applications, such as in micro-grids, plug-in hybrid electrical vehicles, renewable energy sources that include wind energy and photovoltaic systems, low-voltage direct current power system, medium-voltage direct current and alternating current power systems, fuel cell technologies and battery energy storage systems has been detailed by Venkata Suresh and others[35]. The role of Flywheel storage system FESS in power quality improvement, uninterruptible power supply, transportation, renewable energy systems, and energy storage were explained by Mustafa E. Amiryar and Keith R. Pullen besides some commercially available flywheel storage prototypes, along with their operation under each application, are also mentioned[36].Various discussions about categorization of energy storage systems, current and emerging technologies, applications and potential, Economics and markets, socio economic impacts , and environmental impacts were high lighted by Energy storage Council in their report [37].

IV.ENVIRONMENTAL IMPACTS

A stronger evidence base and appropriate assessment/ planning tools e necessary to guide the transition towards a Green Economy by avoiding negative biodiversity outcomes were highlighted by Alexandros Gasparatosa and others[38] .The impacts of different renewable energy pathways on ecosystems and biodiversity, and found that renewable energy sector can affect ecosystems and biodiversity[38]

A study on the south western United states discussed about pollution of water bodies from toxic chemicals used for treating the solar panels and the land prior to solar power infrastructure development. Prolonged drying of ephemeral water bodies due to increasing water use (especially in water-scarce environment such as deserts) has also been highlighted [39].A comparison of effects of fossil fuels and renewable energy like wind energy was studied by Tabassum A and others. A summary the current understanding of these impacts and assessment of how their magnitude is likely to increase with the increase in the deployment of wind turbines. It is seen that the adverse impacts are likely to be substantial and their impacts may increase in complexity and magnitude in proportion to the extent of use of wind as an energy source [40].An assessment of wind farms on bird spices and environmental impacts of wind turbines on wild life effects specifically on bird and bat collision with wind turbines was studied in details by researchers [41,42].Off shore wind farms effect on assessing the effect of these activities on marine species and populations has also been highlighted. [42,43].

CONCLUSIONS

This review paper summarizes the recent developments of hybrid renewable energy systems (HRES) with specific reference to solar photovoltaic and wind energy systems.. Various significant aspects of such systems, such as unit sizing and optimization, control and power management, storage as well as environmental impacts are specifically reviewed. Research on modeling of hybrid energy systems (solar PV and wind energy systems), storage systems and power conditioning units (MPPT converters battery chargers) have been reviewed. Recent research , in the last 10 years have been covered in the review. The individual renewable energies ,Solar and wind, though available in many parts of the world can not be tapped fully because of the uncertainty and seasonality factors. So it is recommended that the wind-hybrid energy systems are one of the best feasible options for the electrification of remotely located, electricity deprived areas because of the cheap and readily available resource. However due consideration of weather data of the region, economic viability including sustainability and storage systems need to assessed.

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