USE OF RENEWABLE SOLAR-WIND HYBRID ENERGY SOURCES TO MEET LOCAL ELECTRICITY DEMAND: CURRENT STATUS AND PROSPECTS

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ABSTRACT

Renewable energy sources are those which are abundantly available in nature. These are solar, wind, sea, geothermal and biomass and energy generated from these sources are carbon free with less pollution and capable enough to compensate the energy generated from coal and other fossil fuels. Wind and solar energy are becoming popular owing to abundance, availability and ease of harnessing for electrical power generation. It is very common to use these two aforementioned sources to generate electricity independently, i.e. solar power acting alone or wind power alone. Sometimes, though, it is desired that two of these renewable energy resources are combined together to generate electricity and these types of systems are called a Hybrid Power System (HPS). Hybrid power systems therefore, provide increased system efficiency and greater balance in supply of energy.

The presentation will be a brief overview of research conducted around the world to design and implement HPS-s that combine wind and solar energy to produce reliable and sustainable electricity for local purposes. Also, information about the research conducting in these directions at the “Novel Alloys Design and Development Lab” (NOVALAB) of Metallurgical and Materials Engineering Department in Middle East Technical University (MetE-METU) and "New Materials and Nanotechnology" Center of Excellence of Azerbaijan Technical University (AzTU) and the details of joint research project proposal within the framework of the Japan-Azerbaijan technical cooperation program in the designing and implementation of solar-wind hybrid energy system at main campus and Techno-park of AzTU in order to supply full electricity demand from green energy sources will be given.

Keywords: hybrid renewable energy sources, photovoltaic power, wind turbine, optimization, power converter

INTRODUCTION

Energy produced from conventional sources has major drawbacks in terms of current and future ecological balance and security, both locally and globally. Therefore, in the modern world where the energy demand is rapidly increasing, the development of the concept and technical principles of using clean, non-polluting and ecologically clean renewable energy sources and the testing and installation of new systems based on renewable sources are among the most important problems. Renewable energy (RE) sources are the sources which can be reproduced or energy that can be replenished at the same rate as it is used. While fossil fuels will be the main fuels for thermal power, there is a fear that they will get exhausted eventually in the next century. Therefore other systems based on non-conventional and renewable sources are being tried by many countries. These are solar, wind, sea, geothermal and biomass. These are also called alternate energy sources or natural or new energy sources but the term renewable has gained the most widespread acceptance. We are using both renewable and non-renewable energy sources with a common aim of production of electrical power or energy.

A hybrid renewable energy source (HRES) consists of two or more renewable energy sources, such as wind turbines and photovoltaic systems, utilized together to provide increased system efficiency and improved stability in energy supply to a certain degree. Compared to standalone wind and solar devices, hybrid renewable energy systems consisting of combined solar and wind energy systems are attractive and suitable for various applications and most commonly for power generation in in rural and urban areas [1-6].

DATA AND METHODOLOGY

Today, the number of articles published on the basis of studies conducted in this direction is increasing rapidly and there are many review articles. The authors of the article [7, 8] emphasized that the investments in the renewable energy sector show a steady increase due to development of new technologies, the rapid increase in the energy demand and globalization. In the review article [9], the authors conducted research on the developments in the renewable energy (RE) field, its contribution to global energy demand, as well as the economic, environmental and technical aspects of solar-wind hybrid systems, using data from articles and official reports published in the last 10 years. The contribution rate of RE to global energy demand is shown in Figure 1.

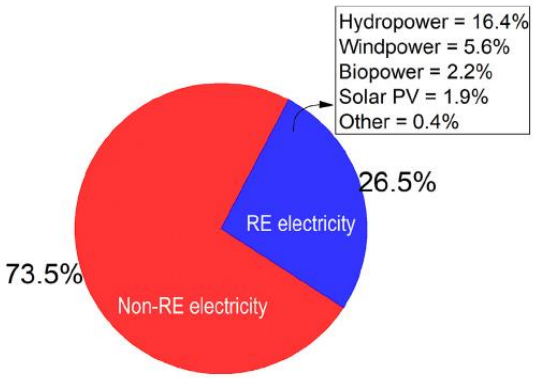

Figure 1. Renewable energy share of global electricity generation [9, 10]

As seen from the figure, the total rate of RE to global energy is 26.5%, of which wind energy is 5.6% and photo-voltaic solar energy (PV) is 1.9% [9, 10]. In addition, statistical

calculations show that by 2040, electricity consumption and energy demand in the world will increase by 40% and 80%, respectively [9, 11]. The rate of increase in the usage values of RE between the years 1990-2020 in the world and on the basis of countries are shown in Figures 2 (a) and (b), respectively [9, 11-13]. Looking at the scales, Figure 2(b) shows that China is in the first place with the highest growth rate, 28 % of the total growth (1990 TWh), followed by the USA and Europe. The globally installed renewable energy capacities are shown in Figure 3.

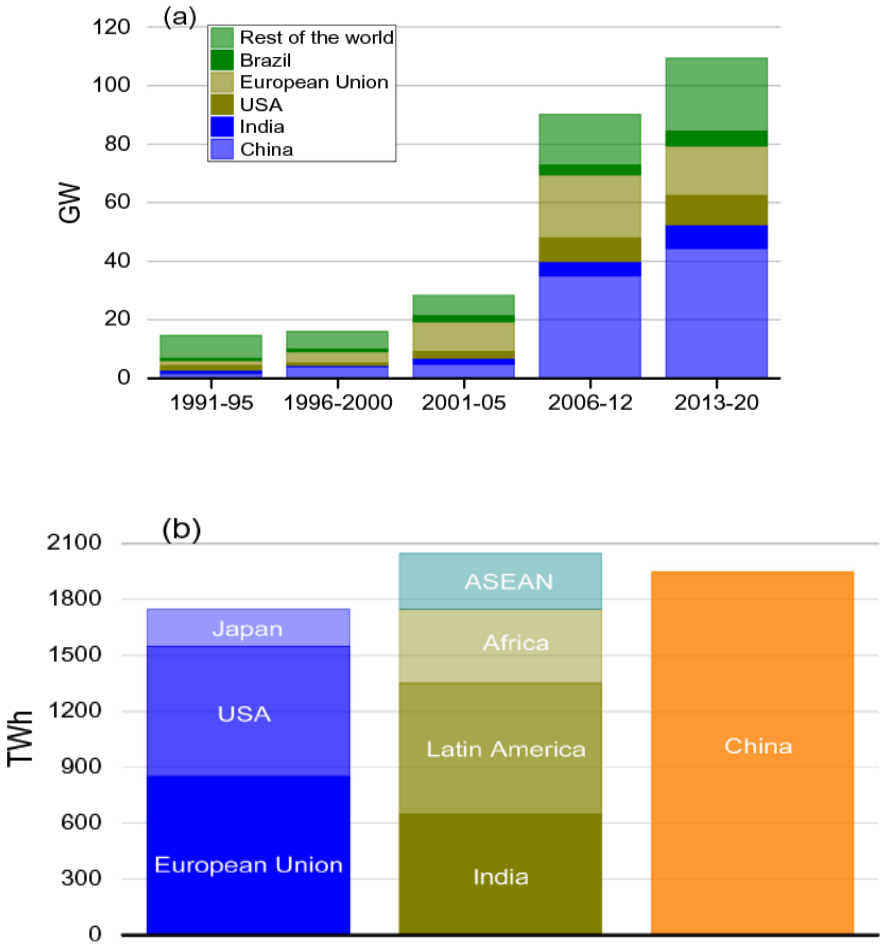

Figure 2. (a) Incremental exploitation of RE from 1990 to 2020 (b) Region wise share of RE [9,11-13]

As can be seen from the figure, solar and wind energy systems are economically viable and commercially acceptable among all available RE sources [9, 14, 15]. It is evident from Figure 3, there is a continuous and steady increase in the installed capacities of solar and wind energy systems. In addition, although the installed capacity of wind energy systems has been greater than solar (PV) as of 2015, it is predicted that the installed solar capacity will exceed the wind capacity in the near future [9, 13].

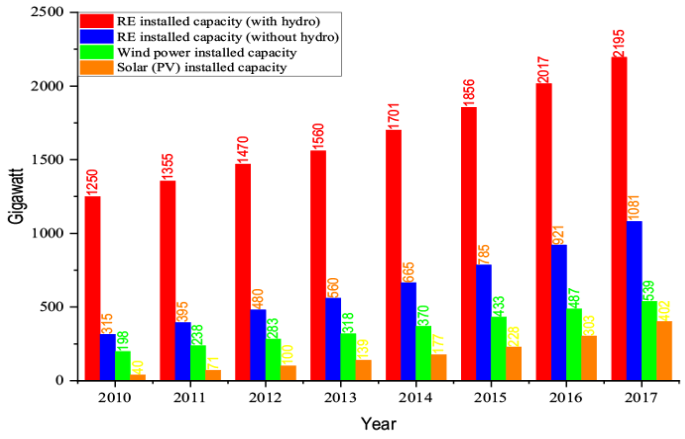

Figure 3. Globally installed renewable energy capacities [9, 14, 15]

The other review article [16] provides a comprehensive review of wind-solar hybrid renewable energy sources (HRES) in terms of power architectures, mathematical modeling, power electronics converter topologies and design optimization algorithms for HRES. In this article, the authors also examine current technical challenges with HRES, future advances in this field, and the scope of future research. Emphasizing that Renewable Energy (RE) sources are the best candidates to provide green energy to tackle the global energy challenge [17], the authors state that from 2017 to 2018, the cumulative global capacity of renewable electricity increased from 2,181 GW to 2,355 GW and electricity generated from renewable energy sourses in 2018 year was 20.5 % of the cumulative electricity capacity. In this context, for example, in the United States, which has the world's most developed economy, RE production in 2018 constituted 17.6% of the total annual production [18]. The renewable energy capacity of the United States and its production from 2009 to 2018 are given in Figure 4 [16, 18]. According to the 2021 Report of the International Energy Agency [16, 19], RE is the only energy source with increasing demand in the world in 2020, while all other fuel consumption has decreased. According to the same Report [19], annual RE capacity additions in 2020 increased by 45% to approximately 280 GW, the highest increase since 1999 compared to the previous year.

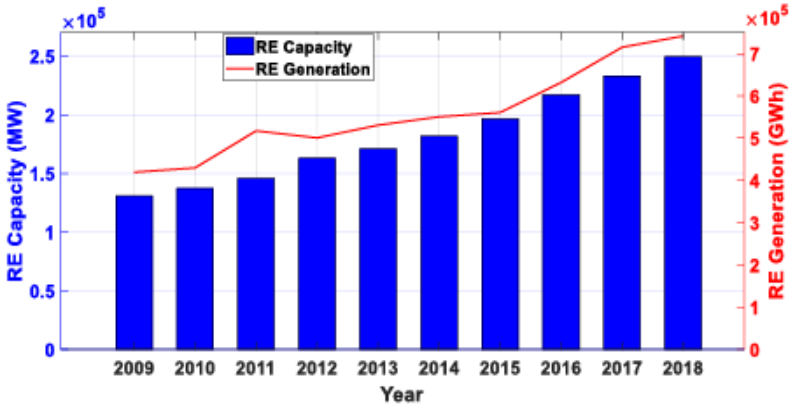

Figure 4. U.S. Capacity and Generation: All Renewables [16, 18]

Moreover, global wind capacity additions increased by more than 90% in 2020 to 114 GW, a 50% increase from the 2017-2019 average [19]. Annual PV and wind capacity additions by the USA are also shown in Figure 5.

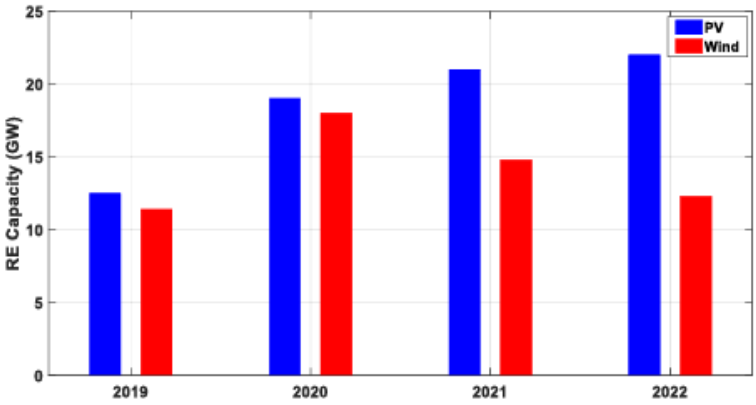

Figure 5. Annual PV and wind capacity additions by the USA [16, 19]

In the 2021 fiscal year budget of the USA, it was announced that 280 million dollars were provided for research in the field of solar energy and its integration into the energy system, and 110 million dollars for wind energy [16, 20]. In addition, according to the data of the US Energy Information Administration (EIA), it is stated that approximately 39.7 GW of new electricity generation capacity will come into operation in 2021 and solar (PV) and wind energy will constitute 39% and 31% of the new capacity, respectively.

RESULTS AND DISCUSSION

Most renewable energy sources such as photovoltaic (PV) array and wind turbines (WT) are known to have unstable output characteristics as their output is highly dependent on environmental conditions, which is the fundamental disadvantage of renewable energy generations [21]. In this regard, the authors of the review article [16] emphasize that the use of hybrid solar (PV) and wind (WT) energy systems is one of the most promising technologies among renewable energy sources to meet the load demand. In this context, it is clear from the data shown in Figure 6 that the penetration of PV and WT energy in general energy power systems is constantly increasing [16, 18].

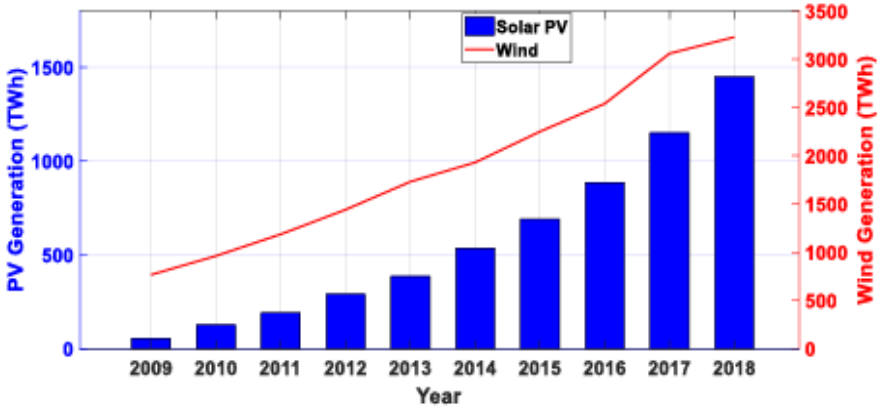

Figure 6. Global Electricity Generation by PV and WT [16, 18]

The most important issues to be investigated for hybrid wind and solar (HWS) generation systems are: power control mechanisms in the system, determining power control strategies, keeping power quality at a satisfactory level, obtaining the maximum available energy from changing wind speed and solar radiation conditions. For desining and installation of the HWS system following informations are necessary: 1) data required for wind system: i)

mean annual hourly wind speed (m/sec) and ii) wind power that can be generated from the wind türbine; 2) data required for solar system: i) annual mean daily duration of sunshine hours and ii) daily solar radiation horizontal (KWH/m^2/day) [22]. A typical hybrid energy generation system and schematic block diagram of the HWS are shown in Figures 7 and 8, respectively which includes following blocks: i) solar panel, ii) wind türbine, iii) charge controller, iv) battery bank and v) inverter.

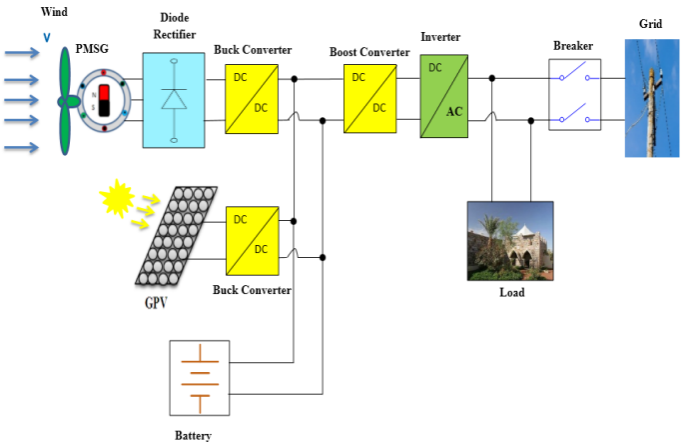

Figure 7. A typical hybrid energy generation system

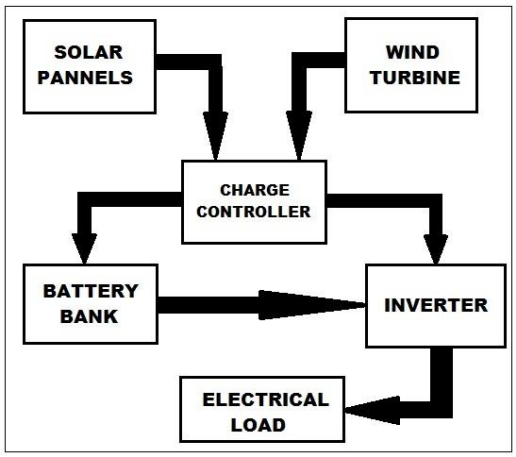

Figure 8. Schematic block diagram of the HWS [22]

A solar panel, as a system that converts solar energy into electrical energy, is consisting of electrically connected in series parallel combinations of several modules to obtain the required amount of current and voltage. Similarly, a wind turbine, as a system that obtains energy from the wind by the rotation of its blades, has two types, vertical and horizontal, and electricity production increases as the wind speed increases. A charge controller is a system that can actively or passively control the source by simultaneously charging the battery and powering the load. The main functions of the controller include not only changing the power according to the load demand, but also the system's over-charge, short-circuit and polarity entanglement protections and functions such as automatic discharging-loading of the system. The size of the battery bank to be used depends on the load requirement and is selected according to the total daily usage watt-hours (Wh) values and the total backup time of the battery. Since the load in the system is running on AC source, inverter is used to convert DC power to AC power.

The total power produced by the HWS system will naturally be equal to the sum of the power produced by the solar (PV) panel and the wind turbine:

$$P_T = N_W P_W + N_S P_S \quad (1)$$

where, P_T, P_W and P_S are the total power, the power generated by wind turbines and solar panels, respectively; N_W and Ns are the number of used wind turbine and solar panels, respectively.

The power extracted from the wind in any wind türbine can be calculated as [22, 23],

$$P_W = \rho\,(A_w)\,(V)^3\,\frac{C_p}{2} \quad (2)$$

in which, P is power (W), ρ is the air density (kg/m³), A_W is the swept area by air (m²) and V is the wind speed (m/s) and C_P is a power coefficient.

The maximum efficiency of a photovoltaic solar panel is given by [22, 23]:

$$\eta = \frac{P_m}{A_c\ E} \quad (3)$$

where, η is efficiency of solar panel, P_m is maximum output power (W), E is incident radiant heat flux (W/m^2) and A_c is area of collector (m^2).

The authors of the present article have so far mostly engaged on the design and synthesis of new materials with superior physical-chemical and mechanical properties for RE systems applications [24-27]. They are currently working on the project of designing and implementing HWS green energy systems to meet all electrical energy demand at AzTU's main campus and Technopark.

CONCLUSIONS

It is evident from the analysis of published research results, that utilizing RE HWS systems for power generation is emerging as a better, more effective and greater efficiency solution than traditional energy sources. Among the most important advantages of HWS systems are its availability at the place where the power is generated, its ability to be installed in places that are difficult to reach, low transmission losses and low energy costs. Also, as a long-lasting system, only the initial investment is needed and it is generally accepted as a good, reliable and affordable system for electricity generation.

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