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Research Paper

Iran's Transition To Wind Energy: Science, Engineering And Policy

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ABSTRACT
In this article, three topics of wind energy science, wind energy engineering and wind energy policy of Iran have been discussed. Deciding on wind energy in the country requires comprehensive information in these three areas. Due to the increase in the capacity of renewable energy in neighboring countries and global energy transition, as well as the high potential of Iran in the field of renewable energy, especially wind energy, its culture in the country and the transfer of concepts in simple language is necessary.
KEYWORDS: ***energy transition, Iran's renewable energy, Wind energy science, Wind energy engineering, Wind energy policy, energy diplomacy, future of energy, renewable energy's scenario.***

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I. INTRODUCTION

Wind energy is an indigenous and homegrown resource that contributes to national security. The impact of wind parks on the natural environment and human activities is low, and wind fuel is free[1]. Wind energy is cheaper and more reliable than other sources of new energy and is accessible in almost all countries. The contribution of wind energy to power generation has grown faster with technological advances in wind power technology in recent decades[2].

II. WIND ENERGY SCIENCE

There are three interdependent, cross-disciplinary grand challenges underpinning wind energy science. The first is the need for a deeper understanding of the physics of atmospheric flow in the critical zone of plant operation. The second involves science and engineering of the largest dynamic, rotating machines in the world. The third encompasses optimization and control of fleets of wind plants working synergistically within the electricity grid. Addressing these challenges could enable wind power to provide as much as half of our global electricity needs and perhaps beyond[3].

2.1 Physiscs of atmospheric flow in the zone

Data for 10% windiest areas taken from WAsP software indicates that Iran's mean power density and mean wind speed at height of 100 meters are respectively equal to 744W/m^2 and 8.41m/s. The four provinces in Iran that have the highest wind power density and average wind speed at that height are South Khorasan, Razavi Khorasan, Sistan and Baluchestan and Gilan, respectively[14]. Figure 1 shows Islamic republic of Iran's mean wind speed map. As we move from light colors to dark colors, the wind speed increases. In general, wind turbines begin to produce power at wind speeds of about 6.7 mph (3 m/s). A turbine will achieve its nominal, or rated, power at approximately 26 mph to 30 mph (12 m/s to 13 m/s); this value is often used to describe the turbine's generating capacity (or nameplate capacity). The turbine will reach its cut-out speed at approximately 55 mph (25 m/s). When wind speeds exceed this, the turbine will stop power production to protect itself from potentially damaging speeds[4]. Turkey with the mean power density and mean wind speed respectively equal to 535 W/m^2 and 7.31m/s , has about 30 times more installed wind power capcity than Iran[14,15].

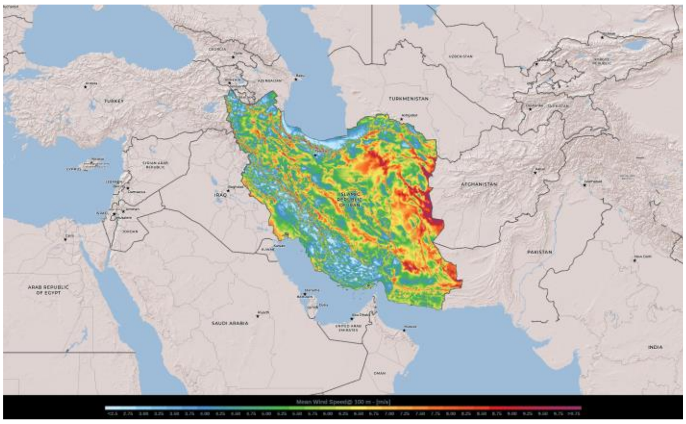

Figure 1. Islamic republic of Iran's mean wind speed map[14]

2.2 Scince of dynamic, rotating wind turbine

The core science needed to advance the next generation of wind energy technology is linked to researchers' fundamental understanding of wind power plant physics, from the source of wind flow in the atmosphere to small scales of flow through the plant, including how the wind plant interacts with that flow. Though the wind industry and wind energy technology have advanced dramatically in recent decades, uncertainty in the science around wind plant physics threatens to limit future innovation in wind turbine and power plant technology that will make wind energy cost competitive nationwide. The ability to truly understand, control, and predict the performance of the future wind plant relies on understanding and tying together a range of physical phenomena from regional weather systems to the wind flow that passes over individual wind turbine rotor blades[5].

2.3 Science of electrical part of wind plant

To overcome the intermittency issue arising from the variable nature of wind energy, and to maintain the reliability and continuous operation of the power system in times of low resource availabilities, a solution would be to combine wind systems with other renewable generation sources such as solar PV, hydro or storage technologies, or with emerging technologies such as hydrogen[6].

2.4 Ministry of science, research and technology's role in wind energy science

The first master's degree program in renewable energy engineering in the country was launched in 2007 at the Materials and Energy Research center, Karaj, Iran. And today it is taught in about 10 universities in the country. It is hoped that by creating a specialized doctorate in this field, researchers will be able to advance its goals[19].

2.5 Wind energy softwares

HomerPRO, RETScreen, FAST,WAsP,WindPRO and WindSim are the most important softwares about wind energy that should be used well.

III. WIND ENERGY ENGINEERING

The wind industry is pushing forward on new technologies on all fronts to increase generation and capacity factor, lower costs, expand storage options, find new locations for economically viable wind farms, and reduce environment impacts[16]. Onshore, longer blades and new access to steady higher-speed winds from taller towers and possibly kites will open up many areas to development. Offshore, increasing the already massive rotor diameters will mean fewer machines to meet the growing demand for renewable energy, and reducing levelized cost of electricity[17]. Furthermore, advances underway in energy storage at wind farms will enable wind to provide electricity when it is needed most, during the hours in the day of maximum system loads usually found in the morning and late afternoon hours. Figure 2, shows trends in wind turbines charectristics over 10 years[7].

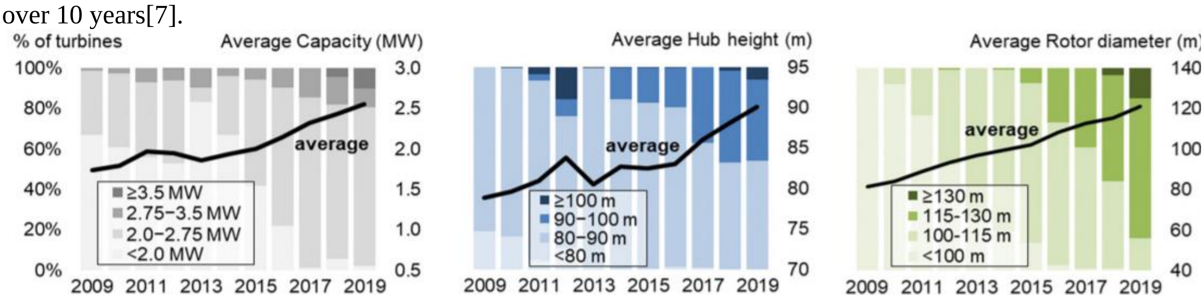

Figure 2. Trends in wind turbine capacity, hub height, rotor diameter[18]

3.1 Rare earth elements in wind energy

With regard to wind energy and e-mobility, rare earth elements are mostly used as raw materials for the manufacturing of permanent magnets, which are used in generators for wind turbines and traction motors for electric vehicles. Since 2005 permanent magnet generators have gained popularity, especially in offshore turbines, as they allow for high power density and small size with the highest efficiency at all speeds, offering a high annual production of energy with a low lifetime cost. Most direct-drive turbines are equipped with permanent magnet generators that typically contain neodymium and smaller quantities of dysprosium. The same, although on a different scale, is true for several gearbox designs. In 2018 generators containing permanent magnets were used in nearly all offshore wind turbines in Europe and in approximately 76 % of offshore wind turbines worldwide. However, it may be possible to replace permanent magnet generators, at least for onshore applications, where the need for powerful generators with a reduced size and weight is not as strict[8].

3.2 Future emerging technologies in the wind power sector

Future technologies consist of airborne wind energy, offshore floating concepts, smart rotors, wind-induced energy harvesting devices, blade tip-mounted rotors, unconventional power transmission systems, multi-rotor turbines, alternative support structures, modular high voltage direct current generators, innovative blade manufacturing techniques, diffuser-augmented turbines and small turbine technologies. The future role of advanced multiscale modelling and data availability is also considered[9].

3.3 Micro wind turbines

Although there is a rise in using solar panel for residential power generation, application of wind turbine is insignificant. In these built-up areas, small size wind turbine has great potential to produce power by operating at low wind speed. The main cause of using wind turbine generator is the less availability of wind energy to produce appreciable power and its economic consideration[10]. Figure 3, shows commercial vertical axis wind turbine.

Figure 3. commercial vertical axis small wind turbines[11]

3.4 Aerodynamics of wind turbines

There are several parameters in the aerodynamic characteristics and design of the horizontal wind turbine. The key sensitive parameters that affect the aerodynamic performance of the horizontal wind turbine, are environmental conditions, blade shape, airfoil configuration and tip speed ratio. Different turbulence models applied to predict the flow around the horizontal wind turbine using Computational Fluid Dynamics modeling are reviewed in articles[12].

3.5 Wind farm civil works infrastructure

Civil works consists of [20]:

1.Roads and drainage

2.Wind turbine foundations

3.Met mast foundations (and occasionally also the met masts)

4.Buildings housing electrical switchgear, SCADA central equipment, and possibly spares and maintenance facilities.

3.6 Offshore wind power

The offshore wind industry is projected to grow from 17 to 90 GW in the next decade, and offshore wind power is expected to account for 15 percent of the global wind industry going forward. The Haliade-X, the most powerful offshore wind turbine in the world, with 220-meter rotor, 107-meter blade, leading capacity factor (63%), and digital capabilities[21]. Gilan and Mazandaran provinces have the potential to install offshore wind farms in the Caspian sea.

3.7 Wind energy power electronics

The wind is a clean, readily available renewable energy source. Wind turbine power is in the range of 1.5 to 12 megawatts (MW), and wind turbines of 5MW and above are for offshore installations. The trend is towards higher wind turbine power, so the potential for power electronics devices will be higher and higher. In wind turbines, power electronic devices include the generator, the AC/DC and DC/AC converters to enable the proper control of the power generation flow[22].

3.8 Wind energy storage technologies

Pumped hydro storage (PHS) is the most mature energy storage technology currently available, and because of its large capacity, it has been the subject of several in-depth studies. Battery storage is becoming a promising technology as it has the benefits of fast response, modularity, controllability, and geographical independence. Compressed air energy storage (CAES) has gradually emerged on the commercial market in recent years as it can be easily controlled at different discharge rates to allow for rapid or mitigated expulsion of compressed air when needed, which allows for better control over power dispatch[14].

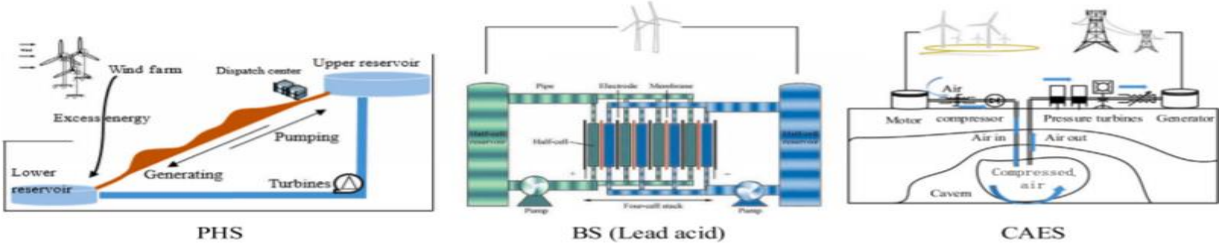

Figure 4. Main energy storage technologies for wind power applications[14]

IV. WIND ENERGY POLICY

Wind energy is considered as a green way to produce electrical energy, as it is estimated that 1 to 2 tons of CO_2 can be saved annually by a 2.5 kW wind energy system and 2.5 to 5 tons using a 6 kW wind system. In some reports, 100 GW is stated as total potential of the country for installation of wind turbines. According to recent studies, there are at least 26 regions consisted of 42 sites in Iran which are endowed with proper status and potential for construction of wind power plants. There are numerous wind energy sites in Iran such as Manjil and Binalood, in Gilan and Khorasan Razavi provinces respectively. The largest number of wind turbines have been installed in Manjil, Gilan province. Although the amount of electricity generated by wind energy is negligible in comparison with other sources of energy, governmental development plans aim to increase its production capacity. These aims have arisen from the obvious fact that Iran has an excellent potential for wind energy. In addition, ministry of energy has made great efforts to promote the wind energy by preparation of wind Atlas of the country utilizing the information gathered from 53 synoptic stations in Iran. In Iran, electricity generation price by means of wind turbines is estimated at 4–5 cent/kWh, provided that foreign exchange rate and fuel costs are fixed; while using steam and gas turbines, cost would be 2 and 2.5 cent/kWh. Adding the imposed social expenses arising from production of CO_2, NO_2, and SO_2, the cost would increase to 3 to 4 cent/kWh. A comparison of these costs reveals the profitability of wind energy systems[13]. The capacity of the country's wind power plants reached 302.82 MW by the end of 2020. According to the official, the mentioned capacity is going to be provided by Zabol Power plant in southeastern Sistan-Balouchestan province. According to the organization, 54 companies are constructing renewable power plants, including solar, wind, hydroelectric, etc. with a total capacity of 229.39 MW across Iran. Over 44 percent of Iran's renewable power plants are solar farms, while 34 percent are wind farms and 12 percent are hydroelectric power plants and the rest are other types[23]. scenario planning is used as a strategic management tool for future analysis of Iran's wind energy. At first, with the precise consideration of expert panel, the critical factors and driving forces were eligibly screened to make future scenarios and then some guidelines for most optimistic, realistic and pessimistic scenarios, proposed in order to eliminate the barriers and promote installed wind power capacity. Due to special conditions of Iran, technology improvements has just been reflected by investment costs for the future of wind power industry and critical factors and driving forces were mainly political and economic. Although forthcoming possible technology improvements in wind turbines capacity and size, advanced monitoring by computer systems and smarter maintenance will evolve wind power industry as is mentioned in renewables global future report[15]. The Feed-in-Tariff (FiT) and the Renewable Portfolio Standard (RPS) are the most popular policies to promote the development of renewable energy[16]. It is strongly recommended that governments should provide loans to the wind energy investors. This strategy can minimize the problem of high initial cost so that it can be much easier to attract the attention of the investors[17].The calculations of 1000 MW wind power plant in Iran by RETScreen software are calculated as follows in figure 5.

Financial viability

Financial parameters

General			
Inflation rate		%	2%
Discount rate		%	9%
Project life		yr	20
Finance			
Debt ratio		%	70%
Debt		$	7,000,000,000
Equity		$	3,000,000,000
Debt interest rate		%	7%
Debt term		yr	15
Debt payments		$/yr	768,562,373
Annual revenue			
Electricity export revenue			
Electricity exported to grid		MWh	2,855,640
Electricity export rate		$/kWh	0.10
Electricity export revenue		$	285,564,006
Electricity export escalation rate		%	2%
Costs | Savings | Revenue			
Initial costs			
Initial cost	100%	$	10,000,000,000
Total initial costs	100%	$	10,000,000,000
Annual costs and debt payments			
O&M costs (savings)		$	300,000,000
Debt payments - 15 yrs		$	768,562,373
Total annual costs		$	1,068,562,373
Annual savings and revenue			
Electricity export revenue		$	285,564,006
Total annual savings and revenue		$	285,564,006

Figure 5. Financial viability

V. CONCLUSION

A level of 100 percent renewable energy would provide Iran with an opportunity to have net-zero carbon emissions and finally contribute to protecting the environment. Transferring renewable energy technology to developing countries is essential.

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