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Iran's Transition to Wind Energy

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Abstract
In this article, the three topics of wind energy science, wind energy engineering, and wind energy policy of Iran are 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 the 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 a 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.*

1. Introduction

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

2. Wind Energy Science

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

2.1. Physiscs of atmospheric flow in zone

The data for 10% windiest areas taken from the WAsP software indicates that the Iran's mean power density and mean wind speed at a height of 100 m 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 [4]. Figure 1 shows the Islamic republic of Iran's mean wind speed map. As we move from the light colors to the dark ones, the wind speed increases. In general, the wind turbines begin to produce power at the wind speed 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 in order 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 the wind speeds exceed this, the turbine will stop power production in order to protect itself from the potentially damaging speeds [4]. Turkey with the mean power density and mean wind speed, respectively, equal to 535 W/m^2 and 7.31 m/s , has about 30 times more installed wind power capcity than Iran [4, 5].

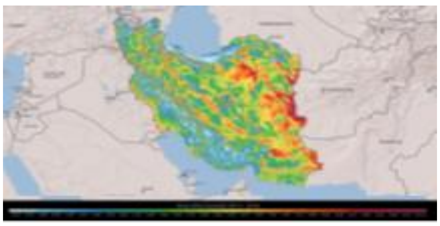

Figure 1. Islamic republic of Iran's mean wind speed map [4].

2.2. Scince of dynamic rotating wind turbine

The core science required to advance the next generation of wind energy technology is linked to the 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 the recent decades, uncertainty in the science around wind plant physics threatens to limit future innovations in the wind turbine and power plant technology that will make the 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 [6].

2.3. Science of electrical part of wind plant

In order 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 the wind systems with other renewable generation sources such as solar PV, hydro or storage technologies, or with emerging technologies such as hydrogen [7].

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, the researchers will be able to advance its goals .

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.

3. Wind Energy Engineering

The wind industry is pushing forward on new technologies on all fronts in order to increase generation and capacity factor, lower costs, expand storage options, find new locations for economically viable wind farms, and reduce environment impacts [8]. 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 reduce the levelized cost of electricity [9]. Furthermore, advances underway in energy storage at wind farms will enable the wind to provide electricity when it is required most during the hours in the day of maximum system loads usually found in the morning and late afternoon hours. Figure 2 shows the trends in wind turbine charectristics over 10 years [10].

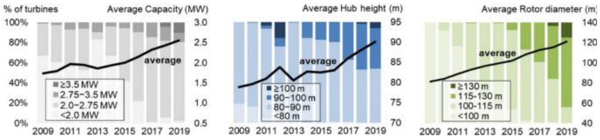

Figure 2. Trends in wind turbine capacity, hub height, and rotor diameter [8].

3.1. Rare earth elements in wind energy

With regard to the wind energy and e-mobility, rare earth elements are mostly used as raw materials for the manufacture of permanent magnets, which are used in the generators for wind turbines and traction motors for electric vehicles. Since 2005, permanent magnet generators have gained popularity, especially in the offshore turbines, as they allow for a high power density and a 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, the generators containing permanent magnets were used in nearly all offshore wind turbines in Europe and in approximately 76% of the 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 [11].

3.2. Future emerging technologies in 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 multi-scale modelling and data availability is also considered [12].

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, the small size wind turbines have a great potential to produce power by operating at low wind speeds. The main cause of using wind turbine generators is the less availability of wind energy to produce appreciable power and its economic consideration [13]. Figure 3 shows the commercial vertical axis wind turbine.

Figure 3. Commercial vertical axis small wind turbines [14].

3.4. Aerodynamics of wind turbines

There are several parameters involved 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 the 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 [15].

3.5. Wind farm civil works infrastructure

Civil works consists of :

1) Roads and drainage
2) Wind turbine foundations
3) Met mast foundations (and occasionally 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% of the global wind industry going forward. The Haliade-X, the most powerful offshore wind turbine in the world, with a 220-m rotor, 107-m blade, leading capacity factor (63%), and digital capabilities [8]. The 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. The wind turbine power is in the range of 1.5-12 megawatts (MW), and the wind turbines of 5 MW 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, the power electronic devices include the generator, AC/DC and DC/AC converters to enable a proper control of the power generation flow .

3.8 Wind energy storage technologies

Pumped hydro-storage (PHS) is the most mature energy storage technology currently available, and due to 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 the recent years as it can be easily controlled at different discharge rates to allow for a rapid or mitigated expulsion of compressed air when required, which allows for a better control over power dispatch [4]. Figure 4 shows the main energy storage technologies for wind power applications.

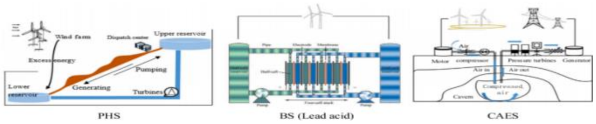

Figure 4. Main energy storage technologies for wind power applications [4].

4. 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 has been stated as the total potential of the country for installation of wind turbines. According to the recent studies, there are at least 26 regions consisting of 42 sites in Iran that are endowed with a proper status and potential for construction of wind power plants. There are numerous wind energy sites in Iran such as Manjil and Binalood in the 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 the other sources of energy, the 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, the Ministry of Energy has made great efforts in order to promote the wind energy by preparation of the wind Atlas of the country utilizing the information gathered from 53 synoptic stations in Iran. In this country, the electricity generation price by means of wind turbines is estimated at 4–5 cent/kWh, provided that the foreign exchange rate and fuel costs are fixed; while using steam and gas turbines, the cost would be 2 and 2.5 cent/kWh. Adding the imposed social expenses arising from the 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 [16]. The capacity of the country's wind power plants reached 302.82 MW by the end of 2020. According to the officials, the mentioned capacity is going to be provided by the Zabol Power plant in SE 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$ of Iran’s renewable power plants are solar farms, while 34% are wind farms and 12% are hydroelectric power plants, and the rest are the other types . 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 the installed wind power capacity. Due to the special conditions of Iran, technology improvements has just been reflected by investment costs for the future of the wind power industry, and the critical factors and driving forces were mainly political and economic.

Although the forthcoming possible technology improvements in the wind turbine capacity and size, advanced monitoring by computer systems and smarter maintenance will evolve wind power industry, as mentioned in the renewable global future report [5]. The Feed-in-Tariff (FiT) and the Renewable Portfolio Standard (RPS) are the most popular policies to promote the development of renewable energy [8]. It is strongly recommended that the 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 [9]. The calculations of 1000 MW wind power plant in Iran by the 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.

5. Conclusions

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

6. Acknowledgment

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