ASSESSMENT AND SIMULATION AN IRRIGATION SYSTEM VIA WIND ENERGY IN MAZANDARAN PROVINCE IN IRAN: A CASE STUDY

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ABSTRACT

Supply of required water to irrigate crops like watermelon which needs a large amount of water is one of the most important issues in developing countries such as Iran. Sufficient wind energy resources in Iran have made it possible to employ this type of renewable energy for different uses especially irrigation. According to the performed research, conducted at the Mazandaran meteorological administration located at the Ramsar city, north of the Iran, it is possible to utilize wind energy in agricultural and industrial in this region. By calculation the velocity of the wind in mentioned station it is found that the wind qualifications are suitable to be employed in most time of the year. Also investigating wind density charts of mentioned region during the year reveals that, aside from September, there is high potential of wind energy utilization for irrigation of different crops such as watermelon

KEYWORDS

Wind energy, wind qualifications, wind density, watermelon, irrigation.

1. INTRODUCTION

Reducing fossil fuel resources, increasing global energy demand and its incremental effect on the environmental pollution has increased the importance of scientific research on renewable energies. Soon or late, fossil fuel resources will be completely exhausted and renewable energies should be replaced to supply energy demand all around the world. In this respect, different studies have been performed on wind energy utilization for irrigation, household and industrial uses in developing countries [1-8].

Regarding Iran's abundant fossil fuel resources and rather low energy price, there are fewer tendencies toward the use of renewable energies. According to the studies, in 2008 A. D. price per cubic meter of natural gas was about 0.85 USD while the mean global price per cubic meter of natural gas was about 6.6 USD [9]. In a similar manner, electrical energy for domestic, agricultural and other uses is estimated 1.65 USD per kilo-watt in Iran while its real mean global price was about 7.36 USD per kilo-watt [9]. Indeed, in Iran, government is paying a high amount of subside to provide energy with low price for people while aided by a basic planning it is possible to spend this budget to promote renewable energies and reducing fossil fuels consumptions.

Utilizing renewable energies in providing drinking water and water for irrigation is broadly investigated by researchers. For instance, Bouzidi et al. explored the possibility of employing wind and solar energies in Sahara region in Algerian [2]. They expressed that, more than 80% of the country have trouble with providing drinking water while the main sources of groundwater are appropriate to be extracted by wind and solar energies for irrigation. Regarding fossil fuels consumption, carbon-dioxide emissions, environmental pollution and water and soil contamination as consequences of using Diesel generators to supply required electricity, they introduced the Sahara region as a high potential area in solar energy which receives 5.5 to 7 KW/m^2 solar irradiance during the day (especially in summer). They found that considered region i.e. Sahara region in Algerian, has low efficiency in wind energy. Manipulating small size turbines is considered appropriate in this region. They also expressed that due to the high price of solar systems, equipments are likely to be stolen and this causes people to be reluctant to use solar irrigation systems in this region but wind energy is safer in this respect.

Saeidi et al. scrutinized the possibility of wind energy harvest at the north and south Khorasan province in Iran [3]. In this respect, they measured the wind speed at different heights. In their study, wind speeds are modeled using weibull probability function. They concluded that mentioned area has good conditions to generate electricity power via wind energy. Regarding wind power density classes published by U.S. Department of Energy, they reported some cities of Khorasan province in Class 2 and some other cities in Class 3. Also, they declared the height of 30m as the best height among investigated heights to harvest wind energy in the region.

Cloutier and Rowley, studied the possibility of renewable energies employing to supply drinking water and other domestic and agriculture uses in sub-Saharan Africa in central Nigeria [4]. They reported that, in the central region of Nigeria, there are less than 6 mm precipitation form November to February and providing clean water for drinking and agriculture is so necessary. Considering high costs of the fossil fuels, they conducted a techno-economic investigation of employing renewable energies instead of fossil fuels for irrigation purpose. They concluded that the amount of received solar energy is suitable in most areas of the region but the available wind energy was different according to the information provided by different stations. They declared that, though the initial costs of irrigation systems set up via solar and wind energies are so much, but their final cost at the end of a 20 years irrigation period will be less than a fossil fuel based irrigation system.

Boudia et al. [5] assessed Algerian wind resource using statistical analysis based on the measured wind speed data in the last decade from 63 meteorological stations distributed over the Algerian territory and 24 in neighboring countries close boundaries. They examined commercial wind turbines for four selected locations in Algeria for their greatest wind potential. Their results led to the actualization of the wind map in Algeria. They also provided energy cost analysis which implies that the four windiest sites have good economic potential to generate electricity with the minimum cost.

Maatallah et al. [6] analyzed the hourly mean wind speed with a 10-min time step provided by the NRG meteorological weather station in the central coast of the gulf of Tunis. Their investigations were focused on the determination of wind speed availability, wind rose and probability of wind power generation at different hub heights. Their simulation of electricity generation and the capacity factor for eight commercial turbines at different hub heights indicates the potential for wind power generation on the central coast of the gulf of Tunis.

As a case study, in this paper, statistical parameters related to the efficiency of wind energy including wind speed and density are studied in details which proves Ramsar city eligibility in hiring wind energy for agriculture uses. Then, considered crop’s water requirements (watermelon in this study) regarding relevant set of parameters are determined. Finally, a general plant is presented to employ wind energy for watermelon planting and irrigation.

2. CONSIDERED REGION DESCRIPTIONS

Mazandaran province is located at the north of Iran and southern coasts of Caspian Sea (Fig.1). This province is one of the populous regions in Iran. Ramsar city is one of the important cities in Iran which its area is about 729.8 Km^2 and its geographic coordination is 36.53^o northern latitude and 50.41^o eastern longitude. This city is connected to the Alborz Mountains from the south and Caspian Sea from the north which makes it talented as a place to harvest wind energy with high efficiency. Niajalili et al [10], already examined the possibility of utilizing solar energy for a rice paddy irrigation at the north of Iran. They stated that, this region is a suitable area to exploit renewable energy. In this study, investigations are focused to evaluate feasibility of employing wind energy to irrigate watermelon planting in a 5000 m^2 garden.

Figure 1. A schematic of Mazandaran province and Ramsar city in Iran

3. WIND ENERGY QUALIFICATION

Iranian people were the first civilization that employed wind power to grind grains [11]. First modern wind power plants in Iran are constructed in Manjil and Roodbar cities in 1985 with a capacity of 1.8 million KW per year [3]. As the first important parameter, wind velocity should be at range of 5 to 25m/s to be appropriate for wind energy use [11]. In Fig.2, daily changes of wind speed are shown for Ramsar city in 2016 [12].

According to Fig.2, in the most time of the year, wind velocity is at the range of productivity. Investigations show that, at least in 235 days of the year, maximum wind velocity was equal or more than 5m/s.

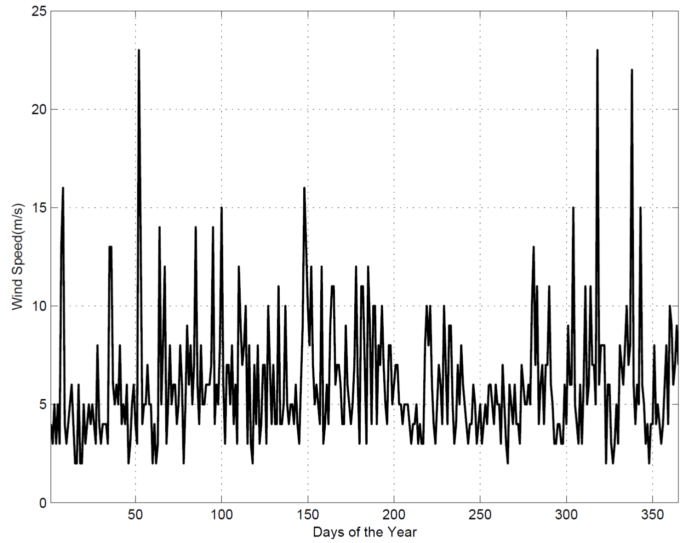

Figure 2. Daily changes of wind speed in Ramsar meteorogical station

The best way to survey wind energy potential in the region is calculating wind density (W/m^2) which is calculated as follows:

$$\text{Wind Density} = P/A = \rho U^3/2 \quad (1)$$

In the above relation, P is the obtained power (W), A is the area of the circle which is swept by blades (m^2), ρ is the air density equal to 1.225 Kg/m^3 and U is the wind velocity. Based on the obtained values for wind density, it is divided to the following categories [3]:

$$\begin{cases} P/A < 100(W/m^2) & \text{Weak} \\ P/A \approx 100(W/m^2) & \text{Good} \\ P/A > 700(W/m^2) & \text{Excellent} \end{cases} \quad (2)$$

In the next step, the wind density for Ramsar city is measured. Fig.3 shows monthly mean wind density in Ramsar in 2016. As it can be seen, aside from September, in other months there is a great amount of wind density to be harvested in wind power.

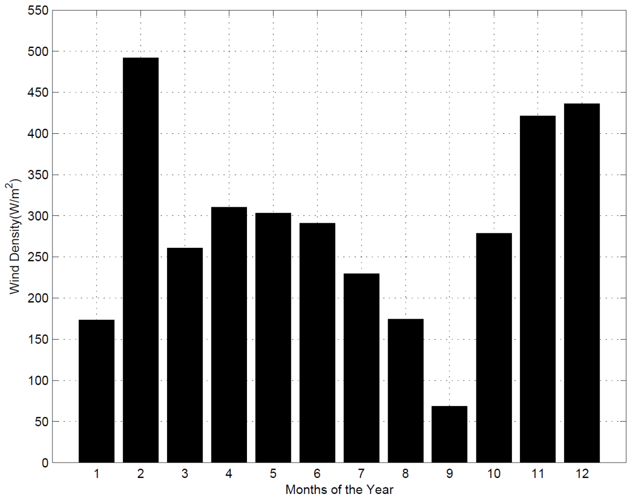

Figure 3. Mean wind density in Ramsar during year (2016)

Measurements of mean wind density show that the maximum reported value for wind density was in February and equal to 462W/m^2 while the minimum value occurred in September and it was equal to 68.56W/m^2. The annual average of the wind density in the Fig.3 is about 300W/m^2. These evaluations imply that the wind density in the research centre is efficient enough to wind energy harvest.

It is worth to mention that in Ramsar synoptic meteorological administration, wind measurement device is installed at a height of 10m. Different studies [3,13-14], have confirmed that with increasing height, wind speed will increase too, so the reported wind density can be increased even to higher values.

4. WATERMELON AND ITS IRRIGATION REQUIREMENTS

Iran is one the main countries in the production of watermelon in the world [15]. Watermelon is one the important branches of vegetables which is planted in a large scale such that, it constitutes 22% of the whole cultivated vegetables all around the world [16]. The amount of cultivation of this crop is estimated about 98 million tons all around the world in 2009 A. D [17]. Watermelon water requirement depends on the weather of considered area to cultivation [18]. North of the Iran because of its sufficient moisture and great sources of underground water is one of the ideal areas to plant watermelon. In Ramsar city, planting watermelon is performed in spring and summer which starts in April and regarding the type of the watermelon and considered area, it lasts about 4 to 5 months.

The amount of water consumption is different to cultivate each crop but the following total relation may be used for watermelon water requirements [19-20]:

$$NWR = ET_C + DP - ER \quad (3)$$

In the above relation, NWR is the net water requirement of the considered crop in millimeter, ET_C is crop evapotranspiration (mm); DP is the deep percolation (mm) and ER is effective rainfall (mm).

The evapotranspiration ratio is the amount of water which is evaporated on the land's surface and the amount of water which is used by plant via transpiration. During the growth season about 30 to 40% of evapotranspiration ratio is related to evaporation [21]. The crop evapotranspiration ratio can be determined by the following relation [22]:

$$ET_C=K_C.ET_0 \tag{4}$$

In the above equation, K_C is a dimensionless parameter known as crop coefficient. Also, ET_0 is the reference evapotranspiration which is determined regarding climatic and meteorological characteristics such as radiation, wind speed, humidity, minimum, maximum and average temperature of each region [22-23]. Dinpashoh et al. have evaluated reference evapotranspiration value for Ramsar city during April to October [23]. According to Dinpashoh et al. this value varies between 55mm in April to 148mm in August.

In the next step, the crop coefficient which has a direct effect on the net water requirement is determined. Because of this parameter importance, different researchers investigated about crop coefficient of watermelon [24-25]. For instance, Edson et al. estimated this value about 0.18 to 1.3 for watermelon [24]. Also Shukla and coworkers obtained crop coefficient of watermelon a value about 0.65 to 1.01 [25].

The other important parameter is deep percolation (DP). Water percolation rate, is in fact the vertical movement of water to the lower levels. The rate of the water percolation depends on the soil type, structure, contents, bulk density, the amount of soil's salt and its other physical properties. In practice, seepage and percolation rates are not easily removable. That is why they are calculated together. According to the studies, the amount of these rates for non-sandy soils is in the range of 1 to 5 mm per day [26]. This rate can be ignored in unsaturated irrigation but it should be taken into account for saturated irrigation [26]. Plusquellec has obtained deep percolation rate for Guilan province near to Ramsar city [27]. He reported this rate equal to 1.6mm for Fouman city and 9mm for regions with higher percolation.

Finally, the effective rainfall (ER) is the amount of provided water via helpful rainfall that can be used for irrigation. Obtaining exact value of this parameter without having detailed quantitative information about rainfall is very difficult. Here, the Smith's relation is used to obtain effective rainfall (ER) by monthly total precipitation (R_{tot}) as follows [28]:

$$ER = 0.6R_{tot} - 10 \text{ for } R_{tot} < 70\text{mm/month} \tag{5}$$

$$ER = 0.8R_{tot} - 24 \text{ for } R_{tot} \geq 70\text{mm/month} \tag{6}$$

In this study, the crop coefficient is set with 1.3 (the maximum reported value for watermelon). The evapotranspiration ratio is considered as what is reported by Dinpashoh et al. for April to August [23]. Also, the deep percolation is set with 5.45mm which is equal to the mean daily value reported by Plusquellec [27]. Finally, the information about total precipitation provided by Guilan Meteorological Administration near to Ramsar city is used to calculate effective rainfall. Mentioned parameters are gathered in Table 1. According to Table 1, the mean daily net water requirement for watermelon planting in a 5000m^2 farm is 47.73m^3 per day. The daily irrigation of watermelon is performed in a continuous 6 hours during growing season.

Table 1. Water requirements of farm during irrigation months

Month	ET_0[21]	K_C	ET	R_{tot}	ER	DP	NWR
April	55	1.3	71.5	23.7	4.22	163.5	230.8
May	91	1.3	118.3	18.9	1.34	168.95	285.9
June	127	1.3	165.1	0.6	0	163.5	328.6
July	145	1.3	188.5	128.9	79.12	168.95	278.3
August	130	1.3	169	18.2	0.92	168.95	337

5. DESIGNING IRRIGATION SYSTEM USING WIND ENERGY

According to the performed investigations, the following plant (Fig.4) is proposed to utilize wind energy for watermelon irrigation.

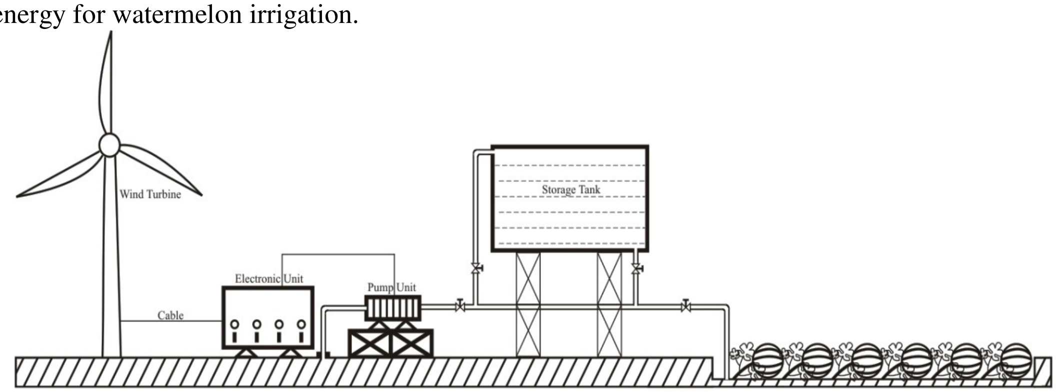

Figure 4. A plant of irrigation system for watermelon irrigation via wind energy

According to Fig.4, generated electricity by wind turbines after passing through control unit reaches the irrigation pump. Considering the fact that Iran's northern regions in terms of underground and surface waters are rich, most of the farms are irrigated by water wells. In this study it is assumed that water is pumped from well to the farm through pipelines. Required power pump can be obtained according to the following equation:

$$P_p = \frac{\rho g h Q}{\eta_p} \tag{7}$$

In the above equation, Q (m^3/s) is the maximum required rate of flow for irrigation, h (m) is water head, g (m/s^2) is the gravity, ρ (kg/m^3) is density of water and η_p is the efficiency of pump. In this study, gravity and head of the pump are set with 9.81(m/s^2) and 9m, respectively. It should be noted that in the north of Iran, the depth of agricultural wells are about 5 to 6m. A friction loss head about 3m is considered for water transport through the pipelines. The density of water is considered equal to 10^3 Kg/m^3. Efficiency of small centrifugal pumps is often about 50 to 70%. In this paper, efficiency of pump is considered 0.6. Calculation of required power pump for watermelon irrigation based on mentioned parameters for a farm with 5000m^2 area is estimated 325 Watts.

A comparison between harvestable power via wind density in Fig.3 and required power pump reveals the possibility of irrigation via wind energy in considered region. To be more specific, regarding the $300W/m^2$ mean annual wind density of Ramsar city and 325W of required power for irrigation, according to Eq. (1), a blade with 0.6m length can afford this amount of energy. In other words, a small size wind turbine would suffice to supply required water for watermelon irrigation in a farm with $5000m^2$ area. In case of rainy days and days when the daily water requirement is provided, a tank is considered to store surplus water. The stored water in the tank may be used later for days with low wind density or days with no wind.

6. CONCLUSION

In this paper, utilizing wind energy to irrigate a watermelon farm with $5000m^2$ area in Ramsar city in the north of the Iran has been statically studied. In this respect, net water required for watermelon planting is determined regarding the evapotranspiration coefficient, deep percolation and effective rainfall. According to the performed investigations, $47.7m^3$/day water is needed to supply watermelon planting in irrigation months in the farm. For this amount of required water, a typical pump with 325Watts power is required. Also, the average annual wind density is estimated about 300Watts which amends the possibility of wind energy utilizing in Ramsar city. Calculations reveal that, available speed and density of wind in most days of the year in Ramsar city can provide this power via a small size wind turbine. It is worth to mention that, wind qualifications in this study are provided by a wind measurement device which is installed in the height of 10m. Considering the fact that wind velocity will increase by increasing the height, for a big size wind turbine with a height more than 10m, this can lead to higher efficiency.

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