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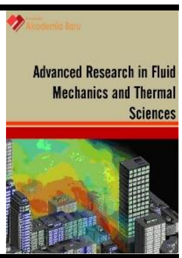

Turbine-Powered Air Water Generator

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ABSTRACT

Water is an integral need for the survival of human life on Earth. Pakistan needs to fulfil requirements of a population of over 200 million along with the added demand of agricultural processes, need to develop unconventional resources of water production for areas that face issues of water shortage. Most of them being rural areas along the southern shoreline of Pakistan despite the presence of Arabian Sea in their vicinity. Southern regions of Pakistan that are along the Makran coastline areas are known to have high humidity (around 70-80%). Also, the coastal areas get a considerable amount of sea breeze for which a turbine can be made to use to harness wind energy required for the operation of this research. Incoming wind enters through the nose cone of the proposed turbine and is then heated by a Peltier device to produce water vapours which trickle down and are collected in the designated collectors. Thus, water for drinking and household purposes can be obtained in this way using renewable energy.

Keywords:
Renewable energy; turbine; wind; water; Peltier device

1. Introduction

Water has not been present on our planet in such vast amounts, life would not have been possible. We need water for every basic need of our lives, at any cost. Global researches have shown significant proofs that the amount of clean water available throughout the globe is scarce and the reserves for drinkable water are getting even smaller with each passing day. Therefore, due to the increasing demand for water with an increasing amount of population, we need alternative resources for producing water [1, 2]. Figure 1 mentioned are the few detailed statistics about the available water resources on Earth. Water resides in 71% of the total surface area of the planet. 97% of the total water available is undrinkable and unusable, without treating it, due to its salinity. The remaining 3% drinkable freshwater that we have, only 0.3% of the water resides in the lakes and rivers, where most of the water we use in everyday lives exists [3, 4].

Moreover, Pakistan is an agricultural country that has scarce water resources as compared to the healthy amount of water supply that is required to fulfil the needs of a population of more than 200

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million. Adding up to all these issues is the lack of national consensus on the construction of dams on the feasible locations due to which Pakistan faces landslides and floods which in turn restricts Pakistan from even storing the rainwater.

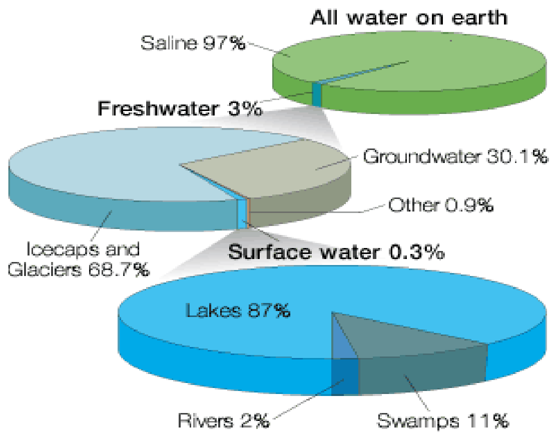

Fig. 1. Classification of water resources

To retaliate against this mainstream issue, this research aims towards an alternative solution for the production of water using an Air Water Generator (AWG) which works on the principle of extracting the water vapour in the air through condensation. Scope of study while considering the methods for the production of water through AWG. The operating time of a Turbine-Powered AWG can be put to use for a longer period as compared to a solar-powered device, which can only operate during daylight for approximately a maximum of 8 hours. In comparison to this, a turbine powered device can be used for more or less, a period of 24 hours, depending only on the wind trends of the area. This device has no complex working mechanism and can easily be operated for household purposes. The configuration of this device has been designed to expand its efficiency and deliver more water per unit of energy provided. To make the device’s operating cost bearable for household purposes [5, 6].

1.1 Atmospheric Water

Water is an essential part of our climate system and it is one of the most important ways of transporting energy in the climate system from one part of the world to the other. Therefore, it has a profound influence on the everyday weather that we experience in our lives. One example of atmospheric water are clouds that are made up of water droplets or tiny ice crystals, whose precipitation leads to rainwater. The other example of atmospheric water is humidity. It is the amount of water vapours that air holds within.

When the water evaporates from the ground, it takes energy in the form of heat from the surface and carries that heat within it until it condenses back into liquid form of water, at which state it releases that energy into the atmosphere. The rate of evaporation increases when the water gets warmer. This explains why the warmer planet means more evaporation, which means more amount of energy is being added to the atmosphere. Also, warmer the air, the more amount of water content it will hold as compared to the chilly air [7, 8].

1.2 Wind Energy

Winds are the result of the inconsistent heat transfer to the atmosphere by the sun. And, are also caused by the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are induced as a result of the difference between the earth's terrain, water bodies, and vegetative cover. The generation of electricity is resulted by harvesting wind flow, or motion energy, using wind turbines [9].

The harvesting of wind energy elucidates the procedure through which wind energy is used to produce mechanical power or electricity. Wind turbines change the kinetic energy of the wind energy into mechanical power. This mechanical power can be used for specific tasks, or the generator can be deployed, which converts this mechanical power into electricity. Also, an additional positive that wind energy holds over solar energy is its availability all over the day as compared to solar energy, which is only bound to 8 hours a day.

1.3 Combination of Wind Turbine with AWG

Air Water Generators (AWGs) are the devices that work on the principle of extracting water from the humid ambient air through the process of condensation. All of the air around us has some amount of water vapours present in it. However, the warmer the air is, greater would be the water content present. They usually work more effectively in areas where absolute humidity is at least 30-40 percent. More preferably, deploying a turbine powered AWG along a coastal area gives an additional advantage of the sea breeze blowing right into the nose cone of the turbine and also provide with more feasible conditions with an increased amount of humid air which would be better for condensation. Integrating a wind turbine with an AWG gives several positive outcomes [10, 11].

Since, for an AWG to produce water from ambient air, it requires the temperature of the ambient air to be above a few degrees above freezing point. Using a wind turbine, it provides us with a suitable height above the ground level to ensure required lower temperatures. The water is produced in an AWG can trickle down the hollow centre of the supposed wind turbine’s pole without using any external energy and be collected at the bottom from where it can be easily used for household purposes. Wind turbines can generally operate all day without any restriction of working hours as compared to solar energy, which can only be harvested during the daylight, which makes up about 7-8 hours a day.

2. Methodology
2.1 Dehumidification Techniques

Following are the methods that an Air Water Generator can use to extract water from the environment.

2.1.1 Refrigeration (Vapor compression system)

The vapour compression system is used to generate drinking water by using a condensation process, which extracts water from ambient air, as shown in Figure 2 [5]. In this type of AWG, a refrigerant is circulated by a compressor over a condenser and it consists of an evaporation coil that cools the surrounding air down causing ambient air to condense to produce water. The resulting water is then kept in a storage tank and then refined and purified to make it drinkable.

The AWG which works on a vapour compression system consists of air conditioner and dehumidifier parts, has enough capability to produce water of such considerable amounts to run a daily household. It also reports the need for drinking water in isolated areas and can be used to reduce the alarming situation of water scarcity. In the AWG, the heat consumed in the evaporation process by the refrigerant cools down the coils due to which the water vapours condense on the coil surfaces. The water generated is then coalesced and then collected in the form of drinkable water.

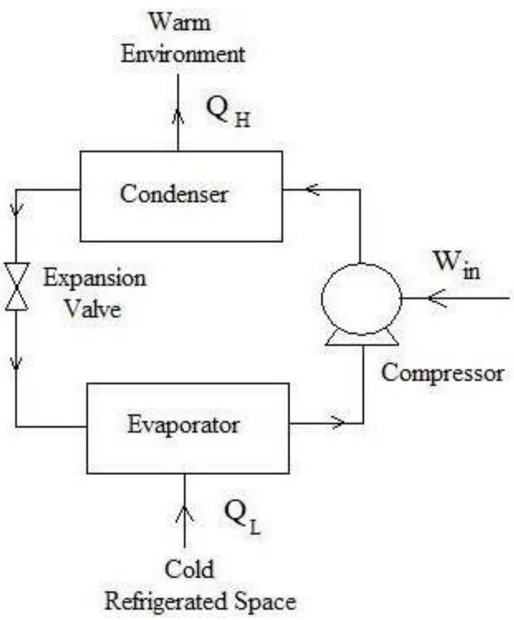

Fig. 2. Vapor compression cycle

2.1.2 Desiccation

In wet desiccation process, chemical substances that are known as desiccants are used. Desiccants are used to absorb water, present as moisture in our environment. Desiccation can be carried out by physical absorption and chemisorption. In this process, the humid air from the environment is exposed to a brine solution, which is used to absorb water vapours from the air stream. The water vapours are then extracted back from the brine solution in the regenerator. This method is comparatively efficient and adaptable towards renewable energy.

Therefore, it is conceivable to compress humid air up to some extent so that it will begin gathering at the ambient temperature. The increase in pressure also rises the dew point of the solution; hence, much compression will result in continuous condensation. The desiccation cycle, as shown in Figure 3 [12].

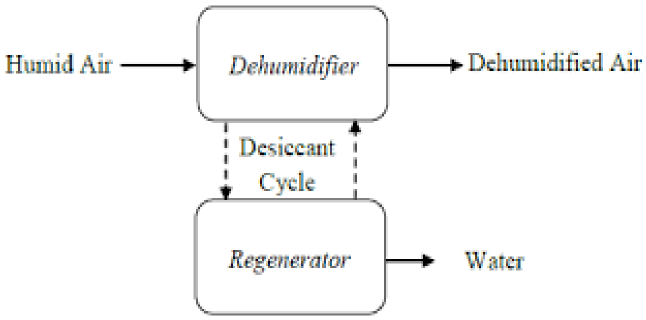

Fig. 3. Desiccation cycle

Nonetheless, compressing air to concentrate water could conceivably require pressures up to multiple times the ambient pressure. This will require an exceptionally strong tank that can deal with over the top measures of stress in its walls. This strategy has the gigantic potential for low vitality requests, particularly if a portion of the vitality in the compressed air utilizing a turbine can be regenerated. The vitality effectiveness of this design has enough potential, yet it depends extremely on compressor and decompressor productivity and humidity. The essential favourable position of pressure dehumidification is the low vitality prerequisite; the main unescapable loss is the pressure applied to the water vapours. In any case, the huge volume of the air processed per unit water delivered amplifies the inefficiency in the compression /decompression cycles. Furthermore, the rate of a generation when driven by natural convection cooling to the environment is unreasonably moderate for remarkable creation; some instrument to accelerate this heat exchange should be actualized, expanding the vitality cost [13].

2.1.3 Thermoelectric cooling

Thermoelectric cooling is a process which devises a different approach to remove thermal energy from a component by applying a voltage of constant polarity to a junction between dissimilar electrical conductors or semi-conductors. It is also known as Peltier Heat Pump. It consists of a matrix of semiconductor pellets sandwiched in between two large electrodes. As shown in Figure 4, a Peltier device consists of two sides; a p-type semiconductor and an n-type semiconductor.

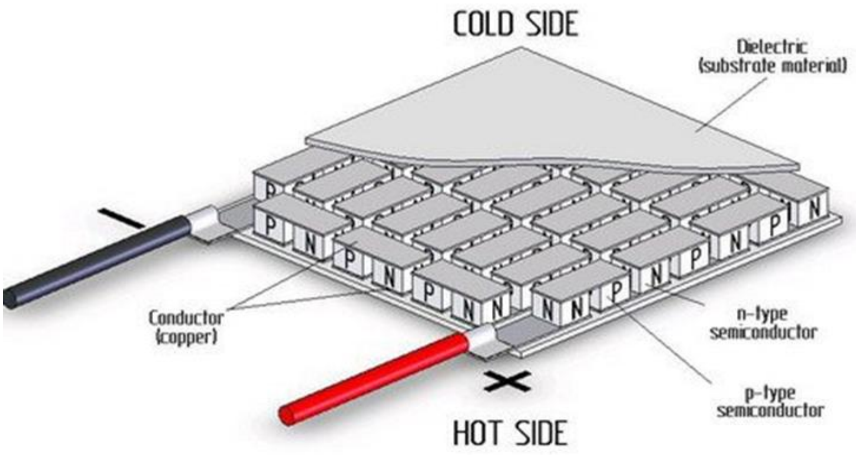

Fig. 4. Peltier device

When the DC voltage source is connected, and the current is allowed to pass through these semiconductors, acting as electrodes, the n-type semiconductor starts getting cooler while the p-type starts absorbing heat and gets hotter. The n-type side of the Peltier is put to make contact with the condenser plates where the temperature drops and water starts to condense. Consequently, the water droplets being formed on the n-type start to coalesce and form water droplets which can then be collected in a container, when they can no longer hold together to stick to the semiconductor’s surface. As for the p-type semiconductor side, it is used to reject heat from the components to the open atmosphere [14, 15].

2.1.4 Process selection

After considering all three available processes for dehumidification air, and taking into consideration all of the consequent advantages and disadvantages regarding every process, decided to choose thermoelectric cooling. The reasons are Peltier device has no moving parts, making it easier to be maintained. It has a comparatively longer life as compared to its corresponding processes. Peltier devices are economical and require less capital and operating cost. The Peltier devices are much more compact and lighter in weight than the equipment required for carrying out refrigeration and desiccation cycles. Refrigeration cycles and desiccation cycles require a complex mechanism of HVAC and desiccants, respectively, whereas, thermoelectric cooling require simple working mechanism which can easily be operated, even by a layman.

2.2 Equipment Design
2.2.1 Wind turbine

The wind turbines work on a simple principle of converting previously explained wind energy into electrical energy. As fans use electrical energy to produce wind, on the other hand, turbines used wind energy to produce electricity. Wind turbines consist of usually a set of three blades connected to a shaft on a rotor. When the incoming wind tangentially strikes the turbine blades, the blades start moving which in turn, moves the shaft along with the rotor. The shaft is connected to a generator on the other hand. When the shaft moves, the generator, on the other hand, starts converting kinetic energy being provided to it, indirectly through the wind, into electrical energy. Figure 5 illustrates the working principle of a wind turbine [16].

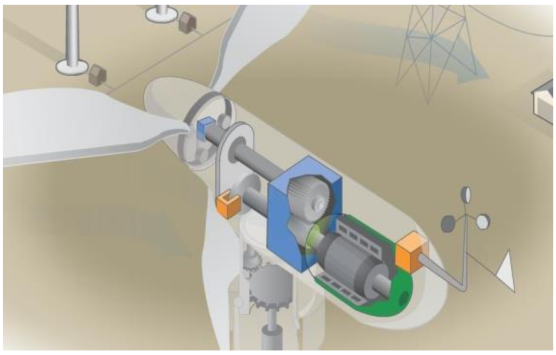

Fig. 5. Wind turbine

The drag and lift forces that are at play in moving the turbine blades. The force that is applied on the blade which is perpendicular to the wind direction is called as Lift Force. It is produced by the pressure difference of the air between either sides of the turbine blade. The other force, which is in the same direction as the wind direction, applied on the turbine blades, is called a Drag Force. To further illustrate the wind trends and their effects on drag and lift forces, as shown in Figure 6 [17].

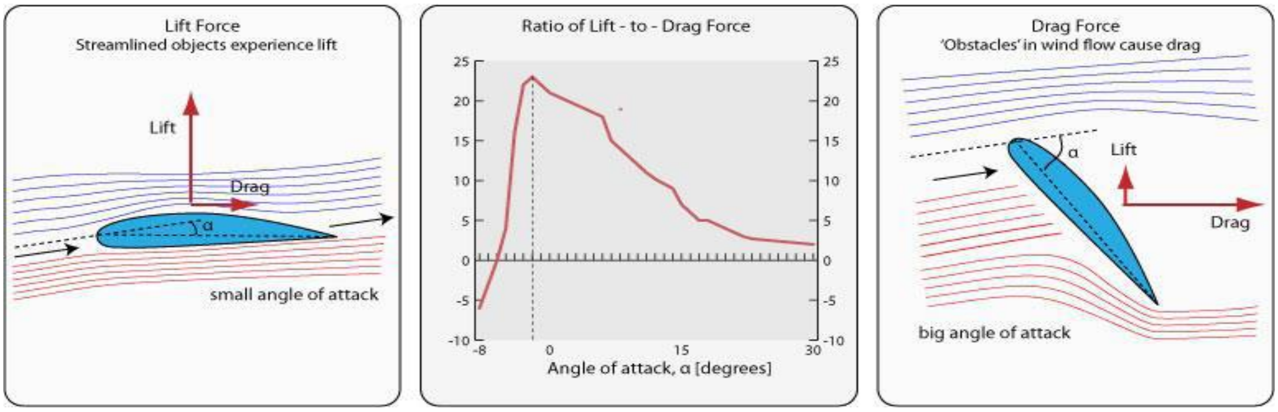

Fig. 6. Drag and Lift forces

2.2.2 Selection of Horizontal Axis Wind Turbine (HAWT)

The factors upon which we chose a Horizontal Axis Wind Turbine (HAWT) instead of Vertical Axis Wind Turbine (VAWT). HAWTs are suitable to be used for large scale energy production, which was our requirement, whereas the VAWTs can only be used for energy and water production on a small scale, hence, choosing HAWT over VAWT was a feasible approach. VAWTs are more reliable to be used for terrains where turbulent air conditions persist whereas our targeted terrain is a coastal area and has no plausible turbulence. Therefore, we chose HAWT to be deployed for the AWG system. HAWTs outlast VAWTs in life span, which also helps us in reducing the operating cost of the turbine [18, 19].

2.2.3 Dynamo selection

Dynamo or Generators are those devices that were connected to the main rotor shaft or the turbine blades that rotate along with the flow of air, as shown in Figure 7. Dynamo is capable of producing electrical energy, in the form of direct current, from mechanical energy, which in case of turbines is provided by the turbine's blades with the help of wind energy. The factors considered for the selection of a compatible generator for the selected Horizontal Axis Wind Turbine to require generator rating is high, to be compatible with the wind turbine. Without high generator rating, a profitable wind turbine cannot be designed. The volt to RPM ratio for a generator has to be high to provide more energy than the input given into it. For instance, for a 1000 RPM turbine to produce 50 V of voltage, need to have a good volt-to-RPM ratio, which is calculated to be 1:20 [20, 21].

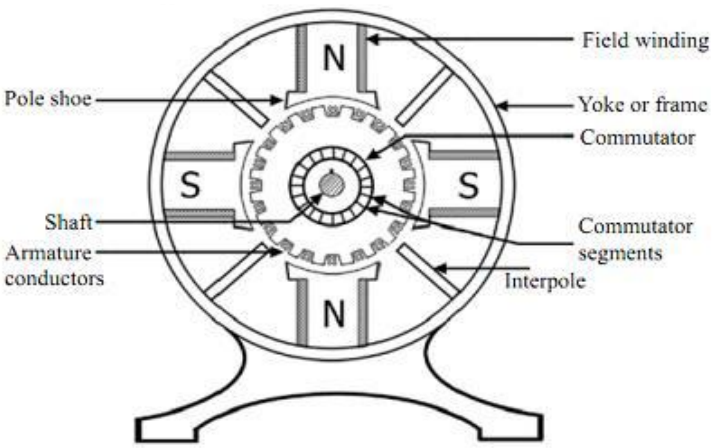

Fig. 7. Wind turbine generator

Low RPM and low torque are designated to be an ideal condition for a wind turbine, since, higher current can be achieved by increasing torque. The response of Permanent Magnet Direct Current (PMDC) generator to varying wind speeds is very quick as compared to other motors because its strong stator field always remains constant giving it an upper hand on being able to respond with better speeds. At a given power, PMDC generators have better efficiency because of the absence of field winding and coil losses. After considering all of the factors above, the Permanent Magnet DC Generator was calculated because of its high compatibility with the wind turbine.

2.2.4 Specifications of selected PMDC generator

Figure 8 represents the AMETEK© PMDC Motor/Generator, rated power of 456 watts, permanent magnet DC motor rated and 38 VDC nominal. The maximum rated RPM is maximum 1300 RPM, armature Current before Permanent Demagnetization is 12 amperes.

Fig. 8. PMDC generator

Torque constant is 50 oz-in per amp, terminal resistance 20 ohms (±20%) and voltage constant is 37 VDC per 1000 RPM. At 38 VDC, with No-load speed, 1100 RPM is generated @ 0.26 amperes, with a 100 oz-in load, the shaft speed generated is measured to be 900 RPM at 2.3 amperes. When tested as a generator at 1000 rpm, the output is measured to be 6.4 amperes at 14.2 VDC [22, 23].

2.2.5 Blade design

The profile and design of turbine blades have clinical significance for its performance and the turbine's efficiency. There are several factors on which the blades' performance is depended. The tip Speed ratio is one of the most basic design parameters based on which the blade design is determined. It is the ratio between rotor blade velocity and relative wind velocity [6, 21]. Figure 9 shows air speed ratio calculations.

$$\lambda = \Omega r / V_w \qquad (1)$$

where λ is the tip speed ratio, Ω is the rotational velocity, r is the radius, V_w is the wind velocity. When R =29 inch =0.73791 m and λ=9.5486.

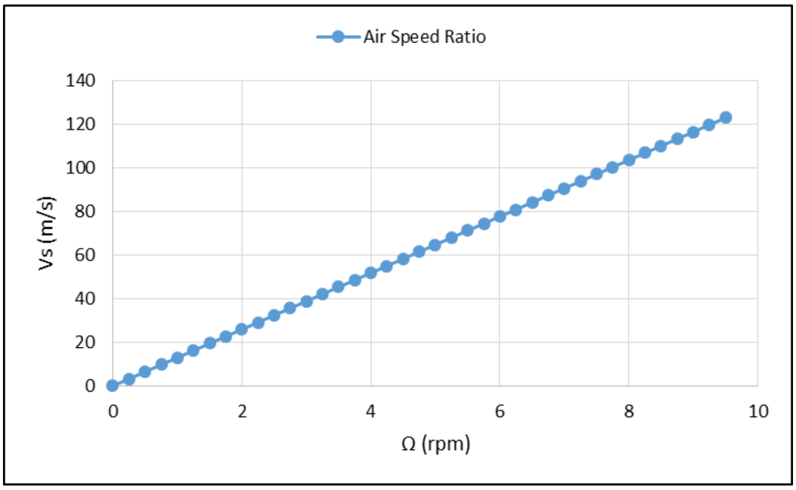

Fig. 9. Air speed ratio

The angle of attack defines the angle between the relative motion of incoming flow of air and the turbine blades' line of sight, which is taken as the reference line for the incoming flow. Figure 6 also represents the effects of drag and lift forces on the blade's angle of attack, which was taken under consideration for the designing of a turbine blade.

The lift created by an air foil area is an element of the approach to the inflowing airstream. The inflow edge of the air stream is reliant on the rotational speed and wind speed at a predefined span. The point of contorting required is needy upon tip speed proportion and wanted air foil approach. For the most part, the air foil segment at the centre point is calculated into the wind because of the high proportion of wind speed to harsh radial velocity. Interestingly the blade edge is probably going to be practically ordinary to the wind. The absolute angle of bend in a blade possibly decreased streamlining the blade shape to cut assembling costs. In any case, this may drive air foils to work at not exactly ideal approaches where the lift to drag proportion is diminished. Such rearrangements must be very much advocated considering the general misfortune in turbine execution and Figure 10 representation of turbine blades. The material of development (Turbine Blade) is Polyvinyl Chloride (PVC) [16].

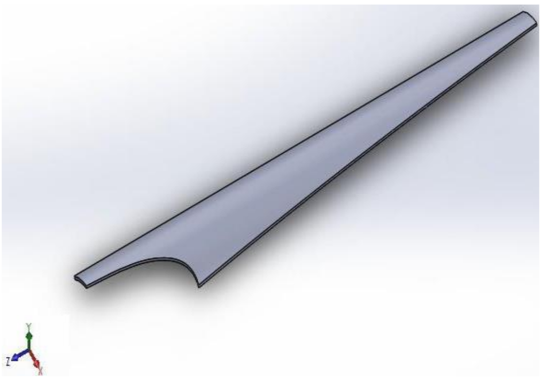

Fig. 10. CAD design of turbine blades

2.2.6 Gearbox design and selection

Since PMDC produces significantly high voltages but has low torque. Therefore, to increase the torque of the rotor shaft to be compatible with the generator, and also to increase the RPMs of the generator, a gearbox design is significant. There are a spur and planetary gears available in the market designed for different purposes, of which the relevant ones, used in wind turbines. The selection criteria are planetary gear systems have higher gear ratios as compared to spur gear in a compact size. Planetary gears, due to its tight arrangement, have fewer losses, which ultimately leads to reduced operating costs. Lesser mechanical losses in planetary gears also lead to better efficiency. On that basis, the Planetary Gearbox System was selected to be deployed in the wind turbine.

The planetary gear system is a type of elliptical gear which could be used in wind turbine power transmission due to its higher precise control. In general, it is suitable for transmission of higher torque and RPM into limited space such as wind turbine nacelle. The Planetary gear system usually consists of 3 Planet gears for better inertial and weight distribution but requires high operational torque which is not compatible with small scale wind turbine. In our design, for the transmission of low RPM such as 100 to 200 RPM produced by rotor blades into 500 to 1000 RPM by gear system requires the gear ratio to be 5:1 to achieve rated specification of 12 to 14 volts. Therefore, two planets design is appropriate for this rated output because they will produce the same gear ratio at low operational torque. The Planetary gear system assembly is much more complex than another gear system due to its casing design, in which bearings and shaft are assembled. Below are the CADs of Planetary Gearbox along with casing Figure 11 CAD of Planetary Gearbox Casing and Split-view of Planetary Gearbox Figure 12 Split View of Planetary Gearbox.

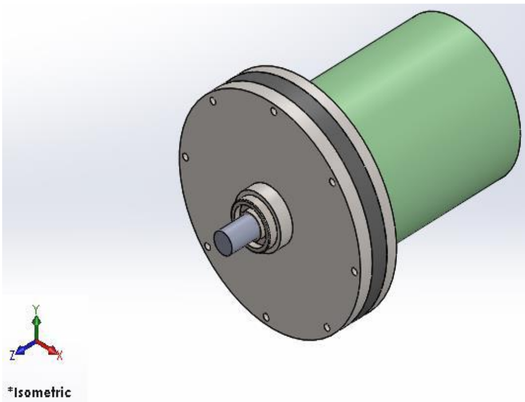

Fig. 11. CAD of planetary gearbox casing

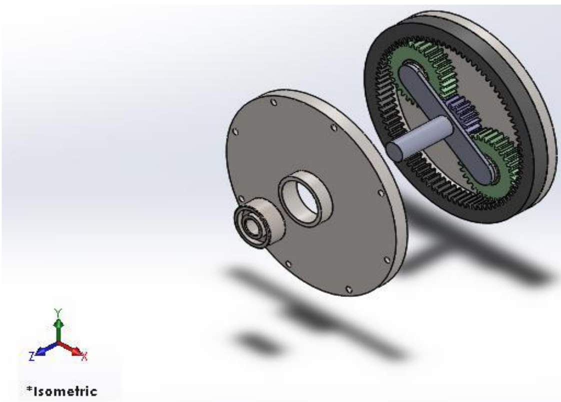

Fig. 12. Split view of planetary gearbox

The Gear ratio:
$Gr = 1 + Nr / Ns$
$Gr = 1 + Dr / Ds$

where Gr = planetary gear ratio, Nr = Number of teeth of the ring gear, Ns = Number of teeth of a sun gear, Dr = Diameter of the ring gear = 126 mm, Ds = diameter of the sun gear = 30 mm. Therefore, Gr = 5.2:1.

2.2.7 Yaw system

The yaw system or yaw drive is responsible for the rotation of the wind turbine rotor towards the wind. The larger wind turbine has an active electronic control yaw system that senses the wind direction and quickly responds by driving the Yaw-motored mechanism. On the other hand, small wind turbine utilizes the wind drag energy to turn the nacelle by acting forces on the boomed tail. Wind turbine when, on rotation, is subjected to several types of loads and stresses (heavy or gusty wind trends), it would damage the mechanical structure and lead towards turbine operation failure. In addition to this, continuous fatigue and vibrational forces do dismantle the entire assembly. The design and selection of a yaw system are quite critical. In our design, nacelle also consists of an AWG which builds extra moment loads and also produces significant restrictions to the free motion of the system. Therefore, better yaw design doesn't result in regular fatigues and rotational mechanism even with slightly gusty wind speeds. Thrust bearings are designed to accommodate axial load in one or both directions, as shown in Figure 13. The single-acting carries the load in one direction while the double-acting carries the load in both directions. There are several design types and configurations to suit a variety of load capacities and applications. The ball thrust bearing is widely used in small wind turbine yaw system due to its simplest construction and assembly and excellent performance towards extreme axial loads but requires oil pan to move smoothly in our design, bearing housing consists of the oil system[6, 21].

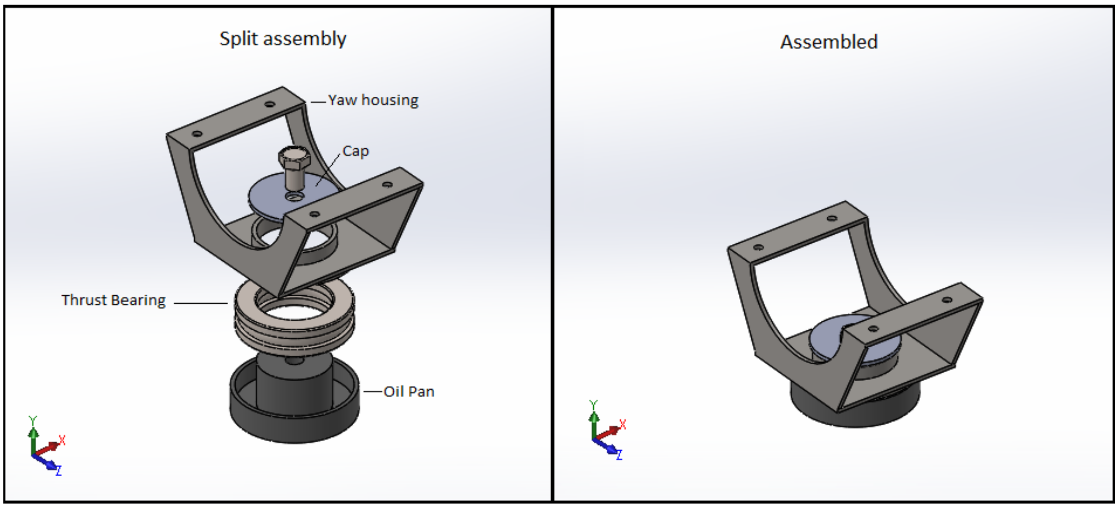

Fig. 13. Assembled and split-view of Yaw system

2.2.8 Tail design

Most small wind turbines are pointed into the wind using a tail assembly as shown in Figure 14. A tail assembly usually consists of the tail fin and tail boom, which are the primary components of the yaw system that keeps the turbine pointed into the wind. Larger turbines generally dispense with a tail because as the turbine size increases, the weight and loads associated with a tail become excessive. In our design, the short tail boom is considered because of the heavy nacelle.

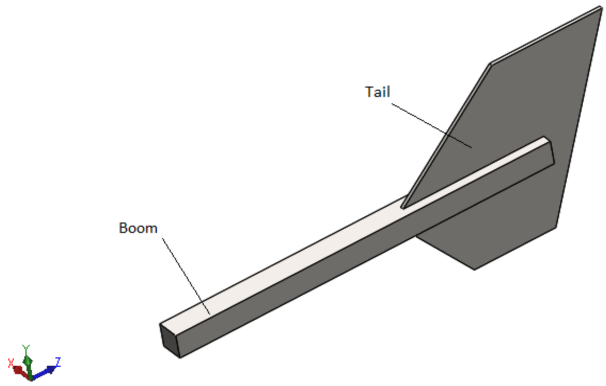

Fig. 14. Tail design

2.2.9 AWG design and selection

When the air enters inside the system through a deliberate channel to drive the air through a carefully selected path, it comes in contact with a pair of Peltier devices whose one side is used for rejecting heat into the heat sink whereas, on the other side of the Peltier, the temperature is dropped up to 70^{o}C. The other side of the Peltier is in contact with the condenser plates where the temperature is brought down to below-zero. As the temperature starts dropping at the condenser plates, water droplets from the humid air start forming. After a significant amount of water droplets are formed, they coalesce and starts protruding until they are too heavy to hold on to the surface of condenser plates. After coalescing to enough large sizes, the water droplets start dropping which are then collected into a collector placed below. As for the dehumidified air, another outlet is made on the other end of the system which provides enough space for the dehumidified air to travel through it to the open atmosphere. The heat sink is incorporated into the AWG system for heat rejection. The purpose of incorporating a condenser plate in an AWG system is to ensure a higher rate of condensation of water from atmospheric air at the surface of condenser plates [24, 25].

2.2.10 Electronic equipment (Sensors)

Electronic equipment, electrical circuits and sensors have been a very instrumental and integral part for the production of Turbine-powered AWG. A buck converter, also termed as a step-down converter, is a power converter which converts from DC to DC source, as shown in Figure 15. It works on the principle of stepping down voltage, also stepping up its current, from its source to output. In this research, two types of buck converters have been used, Buck converter (XL4016) and Buck converter (LM2596) for serving different purposes [9, 11].

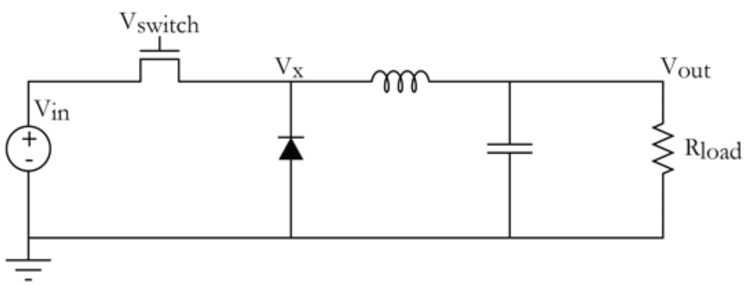

Fig. 15. Buck converter circuit diagram

Watt meter is a device that measures power developed by electrical and electronic systems. In our prototype, Watt meter is composed of two sensors; first is a DC voltage sensor and the other is DC sensor. Therefore, electrical power is the product of voltage (volts) and current (ampere). It is easily measured by measuring readings from voltage and current sensor. To measure the amount of humidity present in the atmospheric air, before and after passing through the AWG system, humidity sensor with model no. DHT22 is used. To record the ambient and AWG system temperatures, temperature sensor probes are used of Model No. DS18B20. Hall sensors are used in our prototype for two purposes. For measuring RPM of condensing inlet channel fan and to measure RPM of the rotor blade.

2.2.11 Prototype design

Figure 16 shows the Air-Water Generator Split-view.

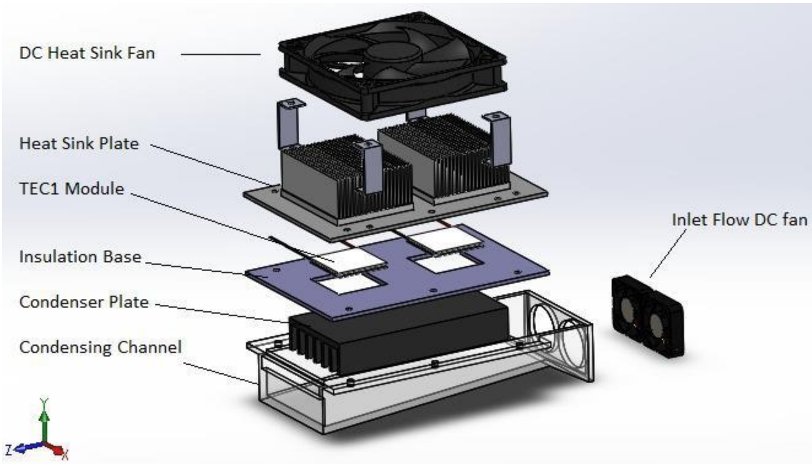

Fig. 16. Split-view of AWG

3. Results and Discussion

The specifications of components for electric supply are 12 V, 6 amperes and DC supply. The Peltier is 2 V, 6 amperes and direct current. Heat sink material of construction is Aluminum. Fans are using two computer DC fans, one is heat rejection fan dimensions are 92mm x 92mm x 20 mm, 12 V, 0.88 amperes, direct current, 180 CFM and another is inlet flow for condensing channel fan dimensions are 70mm x 70mm x 10 mm, 12 V, 0.4 amperes, direct current and 60 CFM. The condenser plate's material of construction Anodized Aluminum (tests with varying frontal areas). Sensors are microcontroller Arduino, DS18B20 temperature probe sensor (temperature sensor), DHT22 humidity and temperature sensor (humidity sensor), 3144 hall sensor (RPM sensor) and L298N motor driver IC - Controlled by Potentiometer (fan speed controller).

3.1 First Test (Using Peltier x1)

The geometry is a frontal area of condenser plate (7 x 7) cm-sq. Wide channel of cross-section area - (90 x 40) mm-sq. Testing of TEC or Peltier on an existing different environmental condition has to be figured out for the design of AWG. The Testing Unit consists of a single Peltier and other major components. The idea is to test AWG on different conditions and parameters. Using Arduino microcontroller, monitor the temperature of the heat sink and condenser plate. Also, measure the humidity of inlet and outlet streams, air flowrate and dew point. The experiment is carried out to observe condensation at different air flows, condenser plate area and time parameters. To set an optimal area of condenser plate for single Peltier. Table 1 data plotting from Arduino Microcontroller is the data obtained from Arduino regarding process conditions.

Table 1
Data plotting from Arduino microcontroller

Sr. No.	CP_Temperature °C	RH_out (%)	Temperature out (°C)	Dew point (°C)	PV
1	11.56	82.0	32.7	29.81	4
2	11.5	82.2	32.8	29.81	2
3	11.44	82.1	32.7	29.81	1
4	11.38	82.2	32.8	29.81	1
5	11.38	82.2	32.8	29.83	1
6	11.38	82.2	32.8	29.81	1
7	11.44	82.0	32.7	29.69	2
8	11.44	82.0	32.8	29.79	3

The test is carried out at different inlet fan RPMs with the power of 72 watts supplied to the Peltier. Within 10 minutes, the condenser plate reaches its maximum cold temperature of an average of 7 °C at 0 RPM of the fan. So, condensation starts at the plate in the form of droplets. Gradually, RPMs of the fan is increased to maintain a sufficient rate of condensation and also, to some extent, constant airflow. After some time, plate temperature reaches to 13 °C whereas, its dew point is around 16-18 °C. Since the approach is set that Tcp = Tdp - 5 °C. After 2 hours, some millimetres of water is collected. Approximately 25 ml of water is produced after 2 hours with a production rate of 12.5 ml/hr. When HS Temperature = 37.44 °C, RH in = 83.9%, Temperature in = 32.9 °C, FS = 0 rpm and FN =0. Hence, due to the larger area of condenser plate, water production is significant but works well at relative humidity higher than 60%.

3.2 Second Test (Using Peltier x1)

The geometry is a frontal area of condenser plate (4.5 x 4.5) cm-sq. Wide channel of cross-section area is (50 x 25) mm-sq. Testing of TEC or Peltier on an existing different environmental condition has to be figured out for the design of AWG. The testing unit consists of a single Peltier and other major components. The idea is to test AWG on different conditions and parameters. Using Arduino microcontroller, monitor the temperature of the heat sink and condenser plate. Also, measure the humidity of inlet and outlet streams, air flowrate and dew point. The experiment is carried out to observe condensation at different air flows, condenser plate area and time parameters. To set an optimal area of condenser plate for single Peltier. In the second test, both, condenser plate area and channel area is kept small to examine condensation of water at maximum airflow ranges in between dew point of 15-20 °C. Therefore, smaller area reaches faster to the cold temperature of 3°C at 0 RPM of air flow. Now, by testing this area at different air flow at an average relative humidity of 64%. It is observed that a smaller area could work at a wide range of ambient temperature and relative humidity but produces less water than a larger one [24, 25]. Also, the compact channel increases the condensation region [3, 10, 19].

3.3 Third Test (Using Peltier x1)

The geometry is a frontal area of condenser plate (7 x 4.5) cm-sq. Wide cannel of cross-section area is (50 x 25) mm-sq. The testing unit consists of a single Peltier and other major components.

Using Arduino microcontroller, monitor the temperature of the heat sink and condenser plate. Also, measure the humidity of inlet and outlet streams, air flowrate and dew point. The experiment is carried out to observe condensation at different air flows, condenser plate area and time parameters. To set an optimal area of condenser plate for single Peltier. In the third test, the area is increased at the same compact channel and tested at cyclic air flow after every 5 minutes with a fan at a total speed of 2700 RPM and 0 RPMs. It is observed that the first droplets form on the plate. Then, the high flow rate increases plate temperature up to an average dew point temperature. Therefore, the plate doesn't hold water for a longer time due to the change in plate temperature every 5 minutes. Hence, the rate of condensation increases due to higher removal of water droplets from the plate. In result to which, 60-80 ml of water is collected in 1 hour. Figure 17 is the experimental data obtained from the tests and their respective graph.

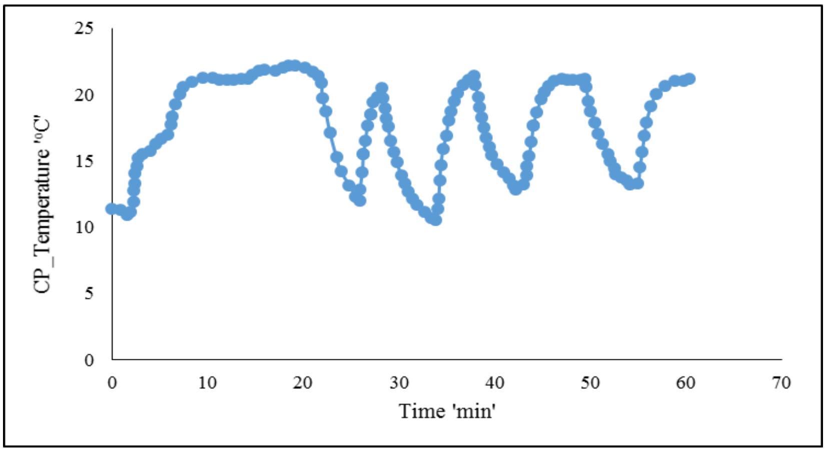

Fig. 17. Condenser plates Temperature vs Time (Cyclic flowrate plot)

Table 2 represents the experimental results at 0 rpm.

Table 2
Experimental results at 0 rpm

Sr.No.	FS_rpm	CP_Temperature (°C)	Time (sec)	Time (min)
1	0	11.56	0 2	0 0.033
2	0	11.50	4 6	0.066 0.1
3	0	11.44	8 10	0.133 0.166
4	0	11.38	12 14	0.2 0.233
5	0	11.38	16 18	0.266 0.3
6	0	11.38	20 22	0.333 0.366
7	0	11.44	24 26	0.4 0.433

Table 3 represents the experimental results at different rpm.

Table 3
Experimental results at different rpm

Sr. No.	FS_rpm	CP_Temperature (°C)	Time (sec)	Time (min)
			330	5.5
1	1500	16.94	332	5.533
			334	5.566
2	1500	16.94	336	5.6
			338	5.633
3	1500	16.94	340	5.666
			342	5.7
4	1500	17.0	344	5.733
			346	5.766
5	2280	17.06	348	5.8
			350	5.833
6	2760	17.37	352	5.866
			354	5.9
7	2760	17.69	356	5.933
			358	5.966
8	2760	17.94	360	6.0
			362	6.033
9	2760	18.19	364	6.066
			366	6.1
10	2760	18.37	368	6.133
			370	6.166
11	2860	18.56	372	6.2
			378	6.233

3.4 Final Test (Using Peltier x2)

The Turbine-powered AWG performance entirely depends upon the appropriate engineering estimation and design. In the previous tests, the experiment of single TEC1 module is carried out to observe its performance on different ambient conditions and controlled parameters. The results showed that single Peltier at above 60% relative humidity produces a fair amount of water using 72 watts of power supply. Therefore, our final prototype design is based on small-scale wind turbine AWG that produces around 2-5 litres of water per day. The generator used has a power rating of 456 watts and our design consists of 200 watts consisting of two TEC1 modules.

The experimental observation, estimation and calculation require a series of tests that would show conclusive results of the prototype design. The wind turbine-powered AWG Prototype is tested on different ambient conditions such as different temperatures, relative humidity and wind speeds. All these tests were being controlled by adjusting the flowrate of inlet condensing channel, according to different rotor powers to produce maximum possible water at limited electrical power supplied by the generator above with a power rating of 456 watts. The prototype is controlled by advance microcontroller Arduino that senses different parameters and show in the serial monitor through which readings are taken and some parameters are controlled. This experiment is carried out to test the performance of AWG at variable power supplied by the electrical generator. Since the power of the electric generator entirely depends upon the RPMs of the rotor blade, the power efficiency E is calculated from Rotor power (Pw) and Electrical power input (Pin) in watts. The calculations of efficiency depend on rotor power and electrical power is tested on roughly average air speeds, as shown in Table 4. When R (in) =29, As =1.71087 m^2, ρa (kg/m^3) =1.225. In this experiment, after the observations, calculations and estimations of the power generation system, the determination of water generation from variable powered AWG is tested on different ambient conditions and parameters. The approach in this type of configuration is the same as the single TEC1 experiment.

Table 4
Efficiency calculations

Sr. No.	Vs (m/s)	pw (watt)	P in (watt)	E (%) x 100
1	8.16	341.62	101	0.2956
2	8.01	323.12	97	0.3001
3	6.68	187.41	83	0.4428
4	6.19	149.12	85	0.57
5	6.67	186.57	88	0.4716
6	6.12	144.12	81	0.5620
7	7.71	288.16	96	0.3331
8	7.01	216.58	73	0.3370
9	6.15	146.25	93	0.6358
10	6.01	136.48	68	0.4982
11	8.27	355.62	112	0.3149
12	7.49	264.19	91	0.3444
13	5.34	95.74	41	0.4282
14	5.09	82.91	36	0.4341
15	3.21	20.79	12	0.5770
16	2.79	13.65	10	0.7323
17	2.18	6.51	3	0.4605
18	3.75	33.15	9	0.2714
19	4.12	43.97	29	0.6595
20	4.56	59.61	21	0.3522
21	6.15	146.25	67	0.4581
22	6.47	170.28	69	0.4051
23	4.27	48.95	31	0.6332
24	4.78	68.66	39	0.5679
25	5.18	87.39	45	0.5149
26	5.8	122.67	67	0.5461
27	7.13	227.89	111	0.4870
28	7.89	308.82	98	0.3173
29	8.28	356.91	123	0.3446
30	8.45	379.35	111	0.2926

The experiment is carried out with high relative humidity of 78% to ensure higher amount of water production and temperature of 32.4 °C with a dew point of 28.4 °C, as shown in Table 5. The plate temperature is maintained at 10°C; the experiment is tested for 5 hours to measure the amount of water produced. Temperature in = 32.4^{o}C, Temperature out = 32.4^{o}C.

The amount of water produced from the Turbine-powered AWG is approximately 630 ml after operating it for a time period of 5 hours, depending upon various conditions and parameters. Especially, due to the variable and limited power from the renewable source, the results are quite justified. From this experiment, it can be estimated that at this production rate of water with higher dew point temperatures that is above 20°C and with average wind speeds above 8 m/s would produce 2 to 5 litres of water per day.

Table 5
Results tabulation

Sr. No.	CP_Temp. (°C)	HS_Temp. (°C)	RH_in (%)	RH_out (%)	Dew Point (°C)	FS rpm	Pot value	FN Value	Time (min)	P in (watt)
1	10.25	37.69	79.8	70.8	28.45	2060	973	201	123.7	146
2	10.25	37.63	79.8	71.8	28.45	1986	982	230	124.3	152
3	10.25	37.63	79.8	71.8	28.45	2130	962	212	126.4	161
4	10.56	37.77	79.8	71.8	28.45	2033	964	201	128.6	143
5	10.56	37.77	79.7	71.8	28.43	2024	974	220	129.2	152
6	10.55	37.19	79.7	71.8	28.43	2027	972	227	130.8	152
7	10.55	37.19	79.7	71.8	28.43	2060	974	221	131.4	142
8	10.44	37.19	79.7	71.7	28.43	2060	974	223	131.7	139
9	10.44	37.13	79.7	71.7	28.43	2010	974	220	132.1	139
10	10.38	37.13	79.7	71.7	28.43	2081	973	218	132.4	147
11	10.38	37.13	79.7	71.7	28.43	1971	983	218	132.9	141
12	10.31	37.13	79.7	71.7	28.43	1998	974	213	133.1	136
13	10.25	37.13	79.7	71.7	28.43	1969	975	211	133.8	138
14	10.25	37.13	79.7	71.7	28.43	2003	962	210	134.6	143
15	10.19	37.06	79.7	71.7	28.43	2060	984	210	134.9	148
16	10.13	37.06	79.7	71.7	28.43	2018	974	210	135.2	145
17	10.13	37.06	79.7	71.7	28.43	2005	973	210	135.6	129

4. Conclusions

As it is a well-established fact that Pakistan and especially, its underprivileged areas have been facing a problem of water shortage which is of grave concern and requires our immediate attention. For this purpose, establishing unconventional resources of water is one of the most necessities that need to be fulfilled. We, in this prototype of Turbine-powered AWG, have provided our utmost efforts to come up with an economical and practical feasible solution that addresses this issue. In this prototype, as already mentioned before, a total of two Peltier devices have been incorporated according to the limited power supply and frontal area provided in this small-scale wind turbine. Several Peltier devices used to play a decisive role in determining the amount of water produced through this process because it controls the process of condensation. As the results show, this prototype would approximately be able to produce 2-5 litres of water even by using small-scale Turbine and lesser number of Peltier devices. For future recommendations, it would be appropriate to increase the number of Peltier devices provided it also has a corresponding required frontal area available to it. This arrangement of an increased number of Peltier devices would certainly give an additional amount of water production capability. Therefore, it might also be able to be used on a large-scale turbine to provide even better process conditions and consequently, produce an even greater amount of water.

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References
[1] Mac Kinnon, Michael A., Jacob Brouwer, and Scott Samuelsen. "The role of natural gas and its infrastructure in mitigating greenhouse gas emissions, improving regional air quality, and renewable resource integration." *Progress in Energy and Combustion Science* 64 (2018): 62-92.

[2] Zafar, Sayem, and Ibrahim Dincer. "Energy, exergy and exergoeconomic analyses of a combined renewable energy system for residential applications." *Energy and Buildings* 71 (2014): 68-79.
[3] Calise, Francesco, Adriano Macaluso, Antonio Piacentino, and Laura Vanoli. "A novel hybrid polygeneration system supplying energy and desalinated water by renewable sources in Pantelleria Island." *Energy* 137 (2017): 1086-1106.
[4] Spang, E. S., W. R. Moomaw, K. S. Gallagher, P. H. Kirshen, and D. H. Marks. "The water consumption of energy production: an international comparison." *Environmental Research Letters* 9, no. 10 (2014): 1-14.
[5] Khaliq, Abdul. "Energetic and Exergetic Performance Evaluation of a Gas Turbine–Powered Cogeneration System Using Reverse Brayton Refrigeration Cycle for Inlet Air Cooling." *Journal of Energy Engineering* 142, no. 3 (2015): 2-11.
[6] Chen, Qiang, Wei Han, Jian-jiao Zheng, Jun Sui, and Hong-guang Jin. "The exergy and energy level analysis of a combined cooling, heating and power system driven by a small scale gas turbine at off design condition." *Applied Thermal Engineering* 66, no. 1-2 (2014): 590-602.
[7] Jacobson, Mark Z., Mark A. Delucchi, Anthony R. Ingraffea, Robert W. Howarth, Guillaume Bazouin, Brett Bridgeland, Karl Burkart, et al. "A roadmap for repowering California for all purposes with wind, water, and sunlight." *Energy* 73 (2014): 875-889.
[8] Jacobson, M. Z., M. A. Delucchi, M. A. Cameron, and B. A. Frew. "Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes." *Proceedings of the National Academy of Sciences* 112, no. 49 (2015): 15060-15065.
[9] Zhao, Haoran, Qiuwei Wu, Shuju Hu, Honghua Xu, and Claus Nygaard Rasmussen. "Review of energy storage system for wind power integration support." *Applied Energy* 137 (2015): 545-553.
[10] Chong, W. T., S. Y. Yip, A. Fazlizan, S. C. Poh, W. P. Hew, E. P. Tan, and T. S. Lim. "Design of an exhaust air energy recovery wind turbine generator for energy conservation in commercial buildings." *Renewable Energy* 67 (2014): 252-256.
[11] Mohammadi, Amin, Mohammad H. Ahmadi, Mokhtar Bidi, Fatemeh Joda, Antonio Valero, and Sergio Uson. "Exergy analysis of a Combined Cooling, Heating and Power system integrated with wind turbine and compressed air energy storage system." *Energy Conversion and Management* 131 (2017): 69-78.
[12] Mohapatra, Alok Ku, and Sanjay. "Analysis of Combined Effects of Air Transpiration Cooling and Evaporative Inlet Air Cooling on the Performance Parameters of a Simple Gas Turbine Cycle." *Journal of Energy Engineering* 141, no. 3 (2014): 1-12.
[13] Mohapatra, Alok K., and Sanjay. "Analysis of parameters affecting the performance of gas turbines and combined cycle plants with vapor absorption inlet air cooling." *International Journal of Energy Research* 38, no. 2 (2014): 223-240.
[14] Othman, Arwa Azhry Mohammed, Rawia Abdalgani, and Mubarak Dirar. "Wind Turbines as Additional Power Supply." *Natural Science* 10, no. 06 (2018): 214-220.
[15] Okoroigwe, Edmund, and Amos Madhlopa. "An integrated combined cycle system driven by a solar tower: A review." *Renewable and Sustainable Energy Reviews* 57 (2016): 337-350.
[16] Bhandari, Binayak, Shiva Raj Poudel, Kyung-Tae Lee, and Sung-Hoon Ahn. "Mathematical modeling of hybrid renewable energy system: A review on small hydro-solar-wind power generation." *International Journal of Precision Engineering and Manufacturing-Green Technology* 1, no. 2 (2014): 157-73.
[17] Yao, Erren, Huanran Wang, Ligang Wang, Guang Xi, and François Maréchal. "Thermo-economic optimization of a combined cooling, heating and power system based on small-scale compressed air energy storage." *Energy Conversion and Management* 118 (2016): 377-386.
[18] Pérez-Collazo, C., D. Greaves, and G. Iglesias. "A review of combined wave and offshore wind energy." *Renewable and Sustainable Energy Reviews* 42 (2015): 141-153.
[19] Bagdanavicius, Audrius, and Nick Jenkins. "Exergy and exergoeconomic analysis of a Compressed Air Energy Storage combined with a district energy system." *Energy Conversion and Management* 77 (2014): 432-40.
[20] Pfenniger, A., R. Vogel, V. M. Koch, and M. Jonsson. "Performance analysis of a miniature turbine generator for intracorporeal energy harvesting." *Artif Organs* 38, no. 5 (2014): 68-81.
[21] Vidyanandan, K. V., and Nilanjan Senroy. "Frequency regulation in a wind–diesel powered microgrid using flywheels and fuel cells." *IET Generation, Transmission & Distribution* 10, no. 3 (2016): 780-788.
[22] Waters, Daniel F., and Christopher P. Cadou. "Engine-integrated solid oxide fuel cells for efficient electrical power generation on aircraft." *Journal of Power Sources* 284 (2015): 588-605.
[23] Najjar, Yousef S. H., and Ghassan M. Tashtoush. "Performance analysis of green engine-driven systems for space cooling." *International Journal of Ambient Energy* 37, no. 1 (2014): 76-84.
[24] Eltahir Khalid Mohammed Abdelgadir, Ali Mohammed Hamdan Adam, Obai Younis, and Ahmed Kadhim Hussein. "Optimum thermal insulation thickness for building under different climate regions - A review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 59, no. 2 (2019): 254-268.

[25] Hussam S. Dheyab, Manar Salih Mahdi Al-Jethelah, Tadahmun Ahmed Yassen, and Thamir Khalil Ibrahim. "Experimental study of the optimum air gap of a rectangular solar air heater." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 59, no. 2 (2019): 318-329.