Design of a Wind-Solar Hybrid Energy Air Conditioning System Using BLDC Motor for the Residential Buildings

A Mohanasundaram (mohanasundaram.a@aalimec.ac.in)
Anna University, Aalim Muhammed Salegh College of Engineering
P Valsalal
Anna University

Research Article

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Design of a Wind-Solar Hybrid Energy Air Conditioning System Using BLDC Motor for the Residential Buildings

A Mohanasundaram* **P Valsalal**

Abstract Air conditioners usages in the homes and offices are the top drivers of global electricity demand for the next three decades. This work proposes an innovative grid-independent, hybrid wind-solar air conditioning model to meet future room cooling demand. This model has 0.3ton capacity, and it is operated with 1.5kW, 48V, BLDC motor drive system. In comparison, with the conventional model, the BLDC based model improves the energy efficiency from 13% to 20% and this model costs 952 USD. A virtual 4kW hybrid model is simulated to analyze the energy generation at the proposed location from different weather conditions to operate this model. This analysis exhibits that a high 57% wind and 69.4% solar energy participation in summer and winter seasons respectively in the total energy generated. This hybrid model and simulation analysis also signifies that the consumer side source generation is a realistic solution to meet the future air-conditioning demand growth due to global warming.

Keywords Hybrid wind-solar virtual · model. Involute wind turbine· Hybrid air conditioning model. Energy·efficiency. Brushless direct current motor.

1 Introduction

Electrical energy demand in many countries keeps increasing because of the world's population growth. The extended summer in countries like India necessitates the air conditioner comfort for more than 4 to 5 months period due to the global temperature changes. Although the start of high capacity power plants on a large scale is reasonably a complicated task to meet this increased energy consumption. (Ershad et al. 2020) analyze present condition, as shown in Fig.1, a high 42% energy participation of thermal (coal) power plants for the electricity and heat generation all over the world creates painful CO_2 pollution and disastrous global warming. (Yenneti et al. 2019) report the impact of rapid urbanization and rapid urban population growth rate on energy consumption and subsequent carbon emissions. It is predicted that India is a rapidly urbanizing country and the country's urban population is expected to grow from 31.6% to 57.7 % by 2050. (Lari Shanlang Tiewsoh 2019) discuss the electricity demand and the Per Capita Energy Consumption (PCEC) in India. The total electricity consumption in the year 2015 is 1000TWh and is expected to increase to 3000TWh also the industrial and domestic demands may be the dominant loads that need to be supplied in the year 2030. (Sahu 2009) mentions a note on PCEC in India and expected CO_2 emissions in the year 2030. The IEA reports state that energy demand for space cooling may consume nearly 40% of electricity growth in buildings in the future.

(Bhoyar et al. 2017) point out that the primary source of the earth's power is from the sun and it is approximately 1.484×10^{18} kWh/year. Only 2.5% of this energy is converted into the energy of motion of the atmosphere. (Ravichandran and David Rathnaraj 2015) report that the daily global radiation at the proposed location (Chennai) is maximum in April (23.35MJ/m2) and minimum in December (15.87MJ/m2).The maximum sunshine duration is observed in February (9.03hour), and in November (5.89h). In March, April and May, the sunshine hours are over 8.6h. In all other periods, sunshine duration is varied between 5.89h and 7.57h.

A hybrid wind-solar system necessitates a minimum number of solar panels and batteries for any proposed capacity compared with standalone systems. (Khare, Nema, and Baredar 2016) review the HRES and state that it can tolerate the rapid changes in natural conditions and suppress the effect of fluctuation on voltage within the acceptable range and it state that the HRES can tolerate the rapid changes in natural conditions and suppress the effect of fluctuation on voltage within the acceptable range. (Hemeida et al. 2020) investigate self-optimized PV and Wind systems. The results are compared and show that HRES is more reliable and efficient. The minimum payback period and energy cost are existing for wind-solar battery combinations. (Chen and Lian 2015) report the noise level in a VAWT model is about 70dB, which is 10dB lower than HAWT. The VAWT is insensitive to the wind direction and it can catch wind from any direction.

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*Corresponding author
E-mail: mohanasundaram.a@aalimec.ac.in
Research Scholar, College of Engineering Guindy, Anna University, Department of Electrical and Electronics Engineering, Aalim Muhammed Salegh College of Engineering, Chennai-55, India.

P Valsalal
E-mail: valsalal@annauniv.edu
Professor, Department of Electrical and Electronics Engineering, College of Engineering, Anna University, Chennai-25, India

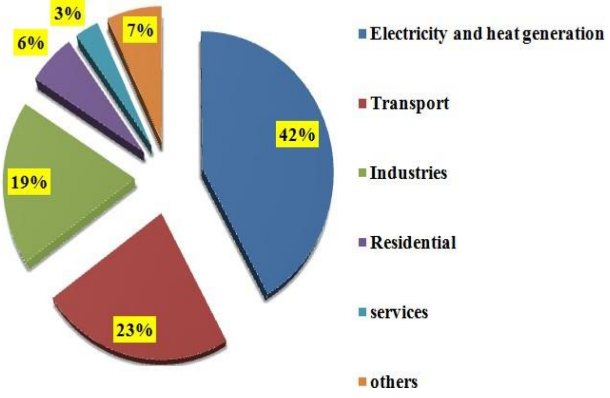

Fig. 1 Sector-wise CO_2 Emission

(Battisti et al. 2018) report that VAWT response times are much greater than horizontal-axis counterparts because of inertia, especially at low wind speeds. The VAWT models are characterized to suit low wind profile urban areas and also to rapid wind varying conditions.

(Peffer et al. 2011) mention the use of electricity for heating nearly doubled from 1985 to 2005. Approximately 20% of the total residential electrical energy is used for cooling; air conditioning makes up the largest single contributor to peak electricity demand. In 2009, nearly 90% of newly constructed single-family homes are expected to include air conditioning. (Waseem et al. 2020) mention the usage of air-conditioners in urban residences in China and annually increased approximately 1% in 1990 and around 100% in 2010. Similarly, the annual sale of air-conditioners in India has increased around 20% in 2010.

2 Methodology

2.1 Block diagram of the proposed hybrid air Conditioning (HAC) system

During the peak of summer, the consumption of energy of air conditioning load is a huge concern for the countries like India. The sudden increase of this load for more than 5 months period creates a noticeable energy deficiency and its associated troubles like black out in the grid energy management (Alhelou et al. 2019). In order to evade all such extremes problems, an energy-efficient HAC system is proposed. This section describes the complete hardware feasibility which is exactly suited for the proposed urban area. The major functional components of the proposed HAC system are arranged in the block diagram, as shown in Fig.2. This model comprises six working stages, namely power source, driving unit, compression, condensation, evaporation, and cooling unit. This model collects energy from Involte Wind Turbine (IWT) and PV panels and charge controller controls the output voltage to 48V and it stored in Lead-Acid batteries. This voltage drives the BLDC motor and it is coupled to the compressor to provide cooling air. The air inside the room can be cooled by using coolant R134Aa gas, which has a high boiling point and low melting point, eco-friendly (Gschrey and Zeiger 2015) and it is present in a liquid state before it reaches the compressor. In this model, air conditioning is done by open drive compressor and the gas used in this is project is R134Aa i.e. tetrafluoro-methane (Goetzler et al. 2016) (Saad et al. 2017) gas, which is a coolant gas mainly used in air conditioning. The compressor is rotated by the BLDC motor using belt transmission (Fig.2) which is selected as per the groove type of the pulley. When the motor drives the compressor, the inlet piston moves in a reciprocating motion, which compresses the inlet R134a gas at high pressure and temperature. The output of the condenser is in the form of gas and partial liquid. For removing this liquid, a drier is placed to filter the air from the liquid. Then the output liquid of the drier is passed through a long capillary tube and it reduces the temperature and pressure of the liquid. When the output of the capillary tube may pass through the evaporator, the cold liquid is blown away by external air using a blower fan at room temperature. When the blower blows external air to cold liquid, then the cold liquid accepts the external air and gets a cool breeze, which exists as conditioned air. The hot liquid from the evaporator is stored in the accumulator, which is a storage tank. It is in the form of liquid and partial vapour and hence it is again passed through the compressor. The cool air is blown up through a blower that operates with a 12V, PMDC motor for regulating temperature.

2.2 Design for Electrical and Mechanical components ratings

This section describes the power rating calculation of electrical and mechanical components, and energy resources requirements necessary to replace the conventional single-phase induction motors operated air-conditioners with equal capacity energy-efficient BLDC motors (Abu Hassan et al. 2015)(Rao 2012). This proposed hybrid solar wind air-conditioning system is designed with a new involute VAWT model.

2.2.1 Design calculation for the Electrical components

In the electrical design calculations, the major components are hybrid energy resources, charge controllers, batteries, and breaker switches.

2.2.2 Air Conditioner Power Rating Calculation

This practical model uses a 0.3 ton car air conditioner model for demonstration. In the hybrid air conditioning system, the energy source calculation is carried as follows,

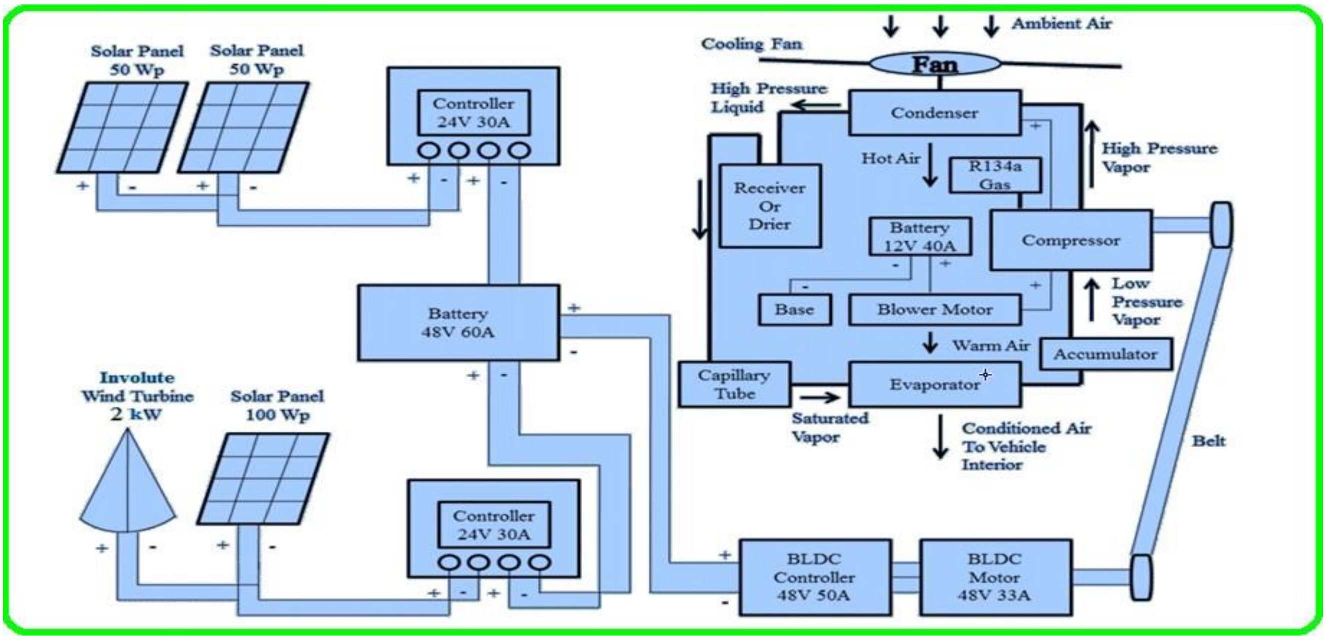

Fig. 2 Functional block diagram for the hybrid air-conditioning system

$$\begin{aligned}
&Power\ needed\ in\ 1\ tons\ air\ conditioner\ = 25\%\ of\ 35\ hp\\
&(35\ hp\ = 1\ Engine\ power\ )\ = \left(25/\ 100\right)\times 35 = 8.75hp\\
&hp\ for\ 0.3\ tons\ air\ conditioner\ = 8.75\times 0.3 = 2.6hp\\
&Power\ for\ 0.3\ tons\ air\ conditioner = 2.6\times 746 = 1.94kW
\end{aligned}$$

In this HAC design for a satisfactory operation, a 2kW wind-solar energy source with at least 10-20% higher capacity is proposed. This proposed air-conditioning model includes a 0.2kWp solar panel and 2kW wind power from IWT with a total capacity of 2.2kW as a renewable energy source. It is always preferred to employ equal percentages of wind-solar combinations for a reliable energy supply. But in this model, to reduce total project investment cost, only 10% of PV power is installed in the proposed work.

2.2.3 Hybrid Energy Resources

This wind-solar renewable energy source gives enough power and energy for the satisfactory operation of the air conditioning system with battery backup. At least 20% of total power needs to be generated through solar panels to improve the cost-effective design and reliable operation of wind energy systems (Zohuri 2017).

2.2.3.1 Design of Involute wind turbine (IWT) model

The Involute wind turbines work on the principle of both lift and drag force and look efficient than the drag force operated H- type VAWT model and the use of drag assisted lift force wind turbines going to be the revolution for the domestic consumers (Jacobs 2010) in the future trends. The Involute wind turbine provides a good power coefficient even at low wind velocity (Anthony et al. 2020) can generate 2kW at the normal wind velocity.

Generated power from the wind for the VAWT model can be calculated using Equation 1.

$$Wind\ power\ generated\ (P_W) = \frac{1}{2}\rho A C_p V^3\quad (W) \tag{1}$$

$C_p = power\ coefficent$

$P_W = power\ of\ the\ wind\ (W)$

$\rho\ =\ air\ density\ \left(kg/m^3\right)$

$A\ =\ area\ of\ a\ segment\ of\ the\ wind\ being\ considered\ \left(m^2\right)$

$V\ =\ undisturbed\ wind\ speed\ (m/s)$

Power calculation for the IWT (Equation 2) model for an average and maximum wind velocity at the proposed location (Mohanasundaram and Valsalal 2019) is shown below,

$$Total\ Surface\ Area\ (S) = \pi r\left(l+r\right)\ m^2 \tag{2}$$

$$\begin{aligned}
&In\ this\ design\ \ D\ =\ diameter\ of\ the\ bladebase\ plate\ = 80\ cm\\
&\qquad\qquad r\ \ = radius\ of\ base\ plate\ = 40cm\ with
\end{aligned}$$

$$\begin{aligned}
&Involute\ rotor\ length\ (l)\ \ = \sqrt{h^2+r^2}\ \ m,\ \ l = 120cm = 1.2m\\
&\quad Area\ of\ the\ rotor\ (S)\ = 3.14\times 0.4\times (1.2+0.4) = 2\ m^2\\
&For\ the\ averge\ wind\ velocity\ of\ 15m/s\\
&\qquad P_W = 0.5\times 1.23\times 2\times 0.4\times 15^3\ = 1660W\ or\ 1.6kW\\
&For\ the\ \max imum\ wind\ velocity\ of\ 24\ m/s\\
&\qquad P_W\ = 0.5\times 1.23\times 2\times 0.4\times 24^3 = 6801.4W\ or\ 6.8kW
\end{aligned}$$

Power from the wind turbine is converted through a PMDC generator of rated capacity 2kW, 24V, 1000 rpm, and the wind rotational speed available for the generator normally available less around 150 rpm only so that 1:7 gear ratios is used to maintain the voltage value near to 24 V for effective battery charging through charge controllers.

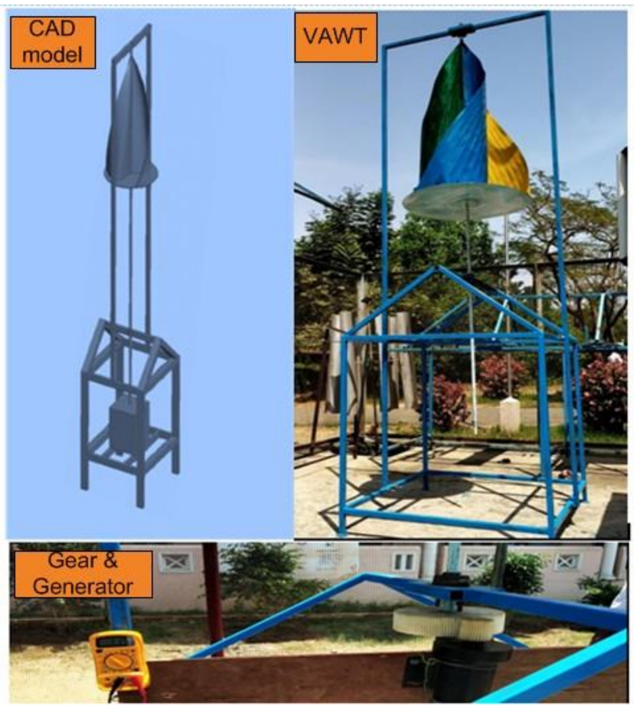

Fig. 3 IWT Practical model with gear and PMDC generator

The IWT model was initially designed in CAD-CREO software and a practical model constructed exactly similar to that as shown in Fig.3. The onetime investment of a wind-solar energy air conditioning system is highly profitable for the consumers and it also provides the solution for energy deficiency. This installed 2.2kW may also be used for other electrical appliances in the home. The voltage readings taken at the designed IWT model for 24V PMDC generator are shown in Table.1.

Table 1 Readings taken at IWT model

SNo	Wind velocity (m/s)	Generated voltage (Volts)	Rotor Shaft rotation(rpm)
1	2.8	7.01	86
2	4.9	11.5	153
3	6.4	18.2	174
4	7.1	23.4	197

This value conveys that this designed IWT model produces enough voltage to operate through the charge controller and effectively charges the batteries to supply energy for the air conditioning system.

2.2.3.2 Design of PV model

A 200W_P Solar panel was purchased to demonstrate this air conditioning system (Fig.4).

Fig. 4 PV Panel with charge controller and 12 V Lead-Acid Batteries

Table 2 Ratings of PV modules used in the hybrid system

Electrical Parameters	Monocrystalline	Polycrystalline
Nominal Power Pmax(watts)	50 Wp	100 Wp
The voltage at Max Power Vmp (Volts)	17.4	11.2
Current at Max Power Imp(Amps)	2.8	5.81
Open Circuit Voltage Voc(Volts)	24	24
Short Circuit Current Isc (Amps)	3.17	6.52
Number of Panels	2	1

But it is advisable to contract an equal rating of solar and wind power resources for the reliable and efficient hybrid energy system. The charge controller prevents overcharging and may protect against overvoltage, which can reduce battery performance or life span, and it may also prevent completely draining a battery (Premkumar, Krishna, and Sowmya 2018). Once the battery approaches full voltage, the controller quickly switches to the panel array and disconnecting the battery bank, which regulates the battery voltage holding it constant. The PWM ensures your battery bank is efficiently charged while protecting it from being over-charged by the PV panel.

Lead-Acid Batteries are used to store energy from the two renewable sources. Five batteries are used in this model and each battery has a capacity of 12V and 60A. In which four batteries are kept a series connection to provide 48V at 60A and another one battery is connected to the Fan blower. All the three PV panels with rated 24V connected in parallel with one of the charge controllers. The VAWT produces 24V, and it is connected in series with a solar panel to make a constant 48V available for batteries, as described in the block diagram.

2.2.3.3 BLDC motor based driver system

A Brushless DC motor comprises a rotor in the form of a permanent magnet and a stator in the form of poly-phase armature windings (Kamran et al. 2018). The BLDC motors are also known as electronically commutated motors (Visconti and Primiceri 2017).

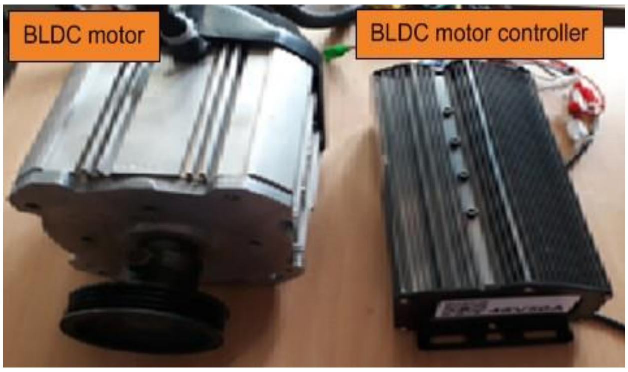

Fig. 5 BLDC Motor with PWM controller

The BLDC motor (Yedamale 2003) is used in this design (Fig.5) for its energy efficient characteristics over other motors. Since torque and speed place an important role in compression.

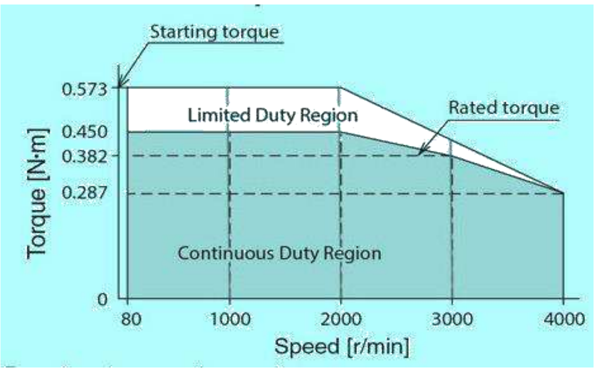

Fig. 6 BLDC Motor Speed-Torque Characteristics

Fig.6 shows the BLDC motor characteristics, and it is suitable to produce flat speed-torque characteristics than the other motor because of no brush fiction to reduce the torque and it is relatively as a high-speed range for supporting the torque. The BLDC motor supports this design by producing low noise to suit for home appliances. The work implemented in the BLDC motor is to run the compressor for a maximum time for better thermal performance and the need to withstand high temperatures. In the BLDC motor, lesser voltage drop on the electronic commutation device improves the efficiency (Magudeshwaran and David 2018) of the motor compared to other motors. As the motor uses the modern permanent magnet with no rotor loss, the output power ratio is also high. This BLDC motor is free from brushes and commutator maintenance is less with an efficient lifetime. The motor uses three Hall Effect sensors to indicate the rotor positions. Two pairs of permanent magnets are used to generate the magnetic flux. Since the motor comprises a six step commutation sequence for each electrical revolutions with the assistance of two pairs of magnets, two electrical revolutions are required two spins the motor once. Hence, the electrical input is converted into mechanical energy, and this mechanical energy is transmitted through a belt drive to run the compressor.

2.2.3.4 Power rating calculation for BLDC motor

The power calculation for the selection of BLDC motor to run the compressor unit of the air conditioning system is preceded as follows:

$$\begin{aligned}&\text{The motor power needed based on the air compressor load},\\&\text{For } 300\ ml\ R134a \text{ gas, power rating needed is } 1.1kW,\\&\text{Supply voltage} = 48V\end{aligned}$$

$$\begin{aligned}\text{Motor current drawn } I &= 33\,A\ (\text{Full load})\\ I_0 &= 2.2A\ (\text{No load})\\ \text{Full load speed } (N) &= 1106\ rpm\end{aligned}$$

$$\begin{aligned}\text{Torque } &= \left(Watts\times 5252\right)/\left(745.6\times 1106\right)\ Nm\\ &= \left(1584\times 5252\right)/\left(745.6\times 1106\right)\\ &= 10.08\,\text{foot pound}\left(1\,\text{foot pound} = 1.3558\right)\\ &= 13.6696\ Nm\\ \text{Motor output power} &= \frac{\left(2\times 3.14\times N\times T\right)}{60}\\ &= \left(2\times 3.14\times 1106\times 13.6696\right)/60\\ &= 1583\ W\end{aligned}$$

Since, high torque is required for HAC system,

hence, current may be high in 2 hp motor and

the current ratings of the motor is chosen as 33A motor

$$\text{Motor supply voltage } (V) = \frac{P}{I} = \frac{\text{Output power}}{\text{Rated current}}$$

$$= \frac{1500}{33} = 48V$$

So, the BLDC motor with 48V, 33A, 8 poles, with a driver

Calculation for batteries

$$\text{Power required for BLDC motor} = 1583\ W$$

$$\text{Motor current } (I) = \frac{1100}{48}\left(48\ V, Battery\right) = 33A$$

$$\begin{aligned}\text{Depth of discharge} &= 0.7,\ Ah = 33/0.7\\ &= 47.14,\ \text{near by available ratings is } 60Ah.\end{aligned}$$

Hence, a BLDC motor with a 1585W, 48V, 33A motor is essential for the proposed 0.3 ton Hybrid energy air-conditioning model.

2.2.3.5 Efficiency comparisons between BLDC and single phase induction motor

Conventional single phase capacitor starts and runs induction motor with a rated capacity of 1.5kW is compared with the same capacity BLDC motor for efficiency calculations, as shown below,

$$\begin{aligned}
&\text{BLDC Motor}\\
&\text{Supply voltage } (V) = 48\ V\\
&\text{Full load motor current } (I) = 33\ A\\
&\text{No load currnt } (I_0) = 2.2A\\
&\text{Full load speed } (N) = 1250\ rpm\\
&\text{Torque produced by a } 1.5\ kW\\
&\qquad \text{motor is } 13.67\ Nm\\
&OutputPower = (2 \times 3.14 \times N \times T)/60\\
&\quad = (2\times 3.14\times 1106\times 13.67)/\ 60\\
&\quad = 1582.4\ W\\
&\text{No Load Power} = 48\times 2.2\\
&\quad = 105.6\ W\\
&\text{Output power} = \text{input power} - \text{No load Power}\\
&\quad = 1584-105.6\\
&\quad = 1476.8\ W\\
&\%Efficiency = \left[\frac{\text{Output power}}{\text{Input power}}\right]\times 100\\
&\quad = (1476.8/1584)\times 100\\
&\quad = 93.2\ \%
\end{aligned}$$

Similarly, the efficiency calculation carried on,

$$\begin{aligned}
&\text{Single phase Induction Motor}\\
&\text{Input power} = 1500W\\
&\text{Torque } (T) = 10.06Nm\\
&\text{Speed}(N) = 1440rpm\\
&\text{Appararent power}(VI)\\
&\quad = 1.5kVA\\
&\quad = 1500/220\\
&\text{Motor current } (I) = 6.52A\\
&\text{Output power} = VI\cos\phi\\
&\quad = 230\times 6.52\times 0.8\\
&\quad = 1199W\\
&\text{Total Losses} = \text{Input power} - \text{Output power}\\
&\quad = 1500-1199\\
&\quad = 301W\\
&\%Efficiency = \left[\frac{\text{Output power}}{\text{Input power}}\right]\times 100\\
&\quad = (1199/1500)\times 100\\
&\quad = 80\%
\end{aligned}$$

A single-phase induction motor with a rated capacity of 1.5kW is compared with the same capacity BLDC motor for efficiency calculations. This results show that the BLDC Motors can give 93.2% efficiency compared with a single-phase induction motor for which it is only 80%. Also, The Induction motors not able to give constant speed-torque characteristics similar to the proposed BLDC motor, and this BLDC motor not suffering like consuming 5 to 7 times the rated current at the time of starting also it not much affected by the power factor. Hence replacing BLDC motors with single-phase induction motors can give large benefits for energy efficiency and reliable and stable operation is concerned.

2.2.3.6 Mechanical components design calculation

The main purpose of the major mechanical components of the hybrid energy air-conditioning system and their functions is described below to understand this demonstration.

2.2.3.6 Calculation for compressor capacity

The basic thumb rule for the condenser is it must be selected 0.5 tons greater than the compressor, so the compressor varies from 0.9 to 1ton. For that reason condenser rating needed is 1.5ton.Thus, the motor rating required for a closed room should be 1.38hp since the air conditioner in open space in practical we need a minimum rated capacity of 2hp or 1.5kW motor because R134a gas temperature varies according to the atmosphere, so that temperature increases and weight increases hence it needs high torque with good hp motor.

$$\text{To convert } kg/cm^2 \text{ to } MPa\ (1kg/cm^2 = 0.098MPa)$$

$$\text{The higher side ranges from } 28 \text{ to } 32\ kg/cm^2$$

$$Assu\min g \text{ higher side value}, 32kg/cm^2 = 3.13MPa$$

$$(1MPa = 10\ bar) \text{ To convert } MPa \text{ to } bar = 3.13\times 10 = 31.3\ bar$$

$$\begin{aligned}
&\text{To convert bar to ton}\\
&1\ bar = 10.19 \text{ tones per meter}\\
&\quad = 31.3\times 10.19 = 318 \text{ tones per meter}\\
&\quad = \left[\frac{31}{1000}\right] = 0.31\ ton\\
&\text{To convert tons to kW} \quad 1\ ton = 3.516\ kW = 0.31\times 3.516 = 1.05kW\\
&\text{To convert kW to hp} \quad 1kW = 1.32hp = 1.32\times 1.05 = 1.38hp
\end{aligned}$$

Similarly, from the thumb rule, the evaporator must be 0.2 tons lesser than the compressor. Hence, the evaporator capacity was decided on to 0.8 tons.

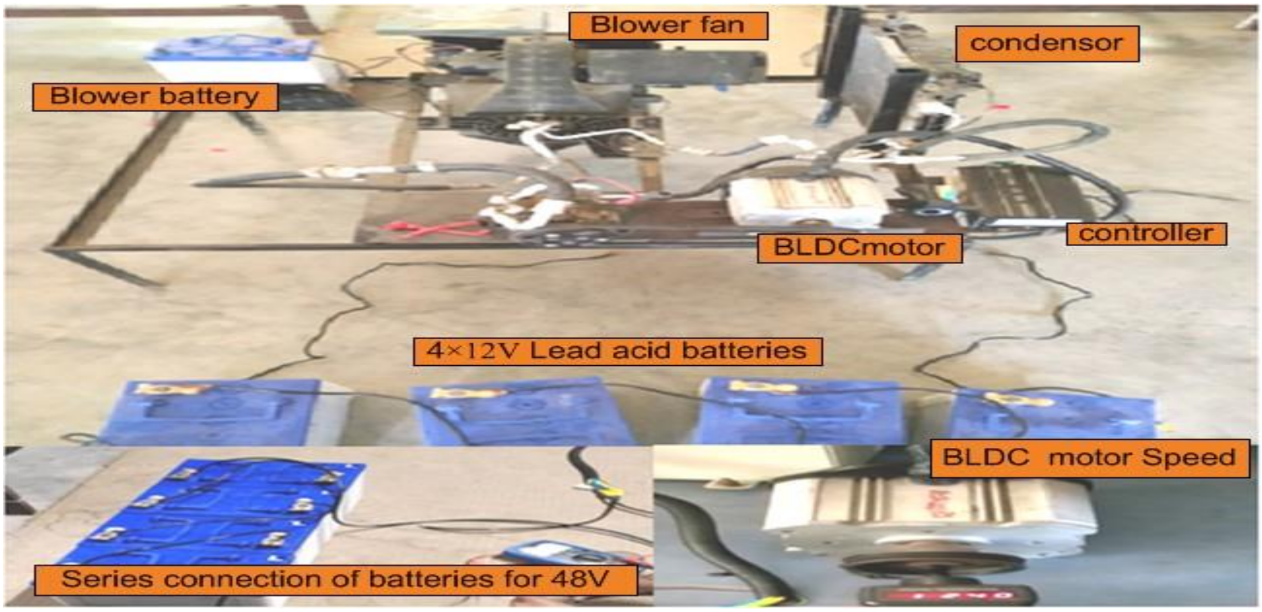

Fig. 7 HAC system experimental model with batteries and BLDC motor

3 Experimental setup

The hybrid energy resources both wind and solar constructed with a maximum power capacity of 2kW and 0.2kWp respectively at 24V, DC voltage from the renewable installation bed at the proposed location as shown in Fig.3.The supply power from the batteries to the motor necessitates copper wire gauges of 6AWG (4.1mm/13.3mm^2) to avoid appreciable voltage drop since the high current flows through a charge controller in the amplitude of 60A at 48V. This voltage from source end through charge controllers applied through four 12V, 60Ah, and Lead-acid batteries, connected in series to make 48V available for the BLDC motor controller through 2 poles 32A miniature circuit breaker (MCB) surface mounted.

A blower fan uses an additional 12V battery connected through MCB for the cooling unit to blow cool air into the room. The air compressor is operated in open belt drive, the cooling of the compressor can be done by the atmospheric air itself and the air conditioner output can be varied by varying the speed of the motor. The capacity of the air conditioner as per the room requirements increased or decreased in this open gas compressor system. This air conditioner filled 300ml of R134a gas in the compressor with suitable arrangements, In this experimental setup, a car compressor is ideal since the BLDC motor wants to connect it in a belt-mode as an open-type compressor. Drier is present in the compressor and a Capillary tube is present inside the Evaporator in the experimental setup. When the supply side MCB switch is closed as shown in Fig.7 the BLDC motor, starts and the belt drive is connected with the compressor, condition the air and the air conditioner gives the pleasant cooling air when the blower fan switch was closed with a less noise level from the blower, this happens smoothly with BLDC motor ratted speed of 1240 rpm measured from a contact type digital tachometer at 48V DC supply from batteries and produces room temperature from 31ºC to 21ºC within in a few minutes during demonstration.

3.1 Estimated cost of HAC model

The estimated cost of the proposed hybrid air conditioning model for its major components is listed in Table.3 and it shows that the approximate cost of the entire model is 952 USD. The estimated cost can be reduced to 680 USD for a one ton air-conditioner when this idea comes to the commercial market. But at present people are spending 340 USD (1USD = ₹73.52) for a 1.0 ton for a source excluded air conditioning system also they have to pay heavy energy prices for their summer comforts.

Table 3 Estimated cost of Hybrid air conditioning model

S No	Description of the Model/ Components	Approximate Cost (in USD)
1.	2 kW IWT model	204.0
2.	0.2kWp Solar panel	136.0
3.	BLDC motor (2 hp) with PWM controller	176.8
4.	Batteries 48V,60Ah	190.4
5.	Mechanical components for 1.0 ton	204.0
6.	Wires, frames and others	40.80
Total Estimated cost (In USD)		952.0

The onetime investment of a hybrid energy air conditioning system interestingly the hybrid air conditioning model cost is only 952 USD, including 25 years of free energy service looking more economical than the conventional air-conditioning system costing 200USD for purchasing appliances alone. This installed 2.2kW renewable wind-solar energy source is not only used for air conditioning purpose and it may operate other electrical appliances in the home.

4 Results and Discussion

The lift & drag force-assisted new involute VAWT model (Anthony et al. 2021) of the rated capacity of 2kW can give efficient energy conversion (Oliver Hammond and Shelby Hunt 2014) because it gives a maximum of 24V at a normal 7m/s wind speed, as shown in Table.1. Hence, the proposed involute VAWT model is suitable for the low wind urban area. In a country like India, the extended summer starting from March to July for more than five months period can harvest wind energy both in day and night time unlike the solar model alone. As the paper stated earlier that we need to find the solution for a problem from where it is originated, thus the air conditioner role is heavier during the summer period, coincidentally the wind season also attains its peak during this time. Hence the wind energy is the right choice to support air conditioner load during the heavy summer. Similarly, high-efficiency solar panels with reduced prices available in the energy market that motivate the hybrid energy air conditioning system and one for the global consumers.

4.1 Analysis of hybrid wind-solar integration system in the proposed air conditioning model

A hybrid combination of wind-solar energy with rated 4kW (Vatti 2013) power may be sufficient to run electrical appliances and air-conditioning load in a home environment. This analysis considers the random incidence of wind speed and good availability of solar irradiance in the proposed location (Anthony et al. 2021). This section describes the analysis of energy generation for an urban area environment with a virtual simulation 2kW wind-solar model power capacity for different weather such as summer and winter season. Both these wind-solar models are described through appropriate mathematical equation to give power conversion from input and output relations (Anthony et al. 2021)·(Anthony Mohanasundaram and P.Valsalal 2019). This simulation analysis considers two notable seasons in the proposed location with dominant summer for 8 months and the remaining 4 months exists as a winter. A hybrid virtual model shown in Fig.8 comprises a wind-solar input section, wind-solar mathematical model and an energy calculation block.

Wind-solar input section collects wind speed input in m/s and solar irradiation in W/m^2.This block provides minimum and maximum wind speed and solar irradiation details of the proposed urban location for winter and summer seasons. Wind-solar energy block collects power output from the virtual model and calculates energy by the integration over the simulation (hourly) time. Fig.9 indicates the hybrid wind-solar power generation in a day for 24 hours in the simulation for random input between maximum and minimum values. This virtual model is designed to give combined maximum power of 4kW and minimum of 0kW (indicates no renewable power) and integrating this power over time in 24 hours gives the energy generated in a day in kWh or units from the wind-solar resources. The simulation output waveform shows that wind energy produces its maximum power when the solar energy is not available and its combined energy peaks at 12Noon to 6PM during which these hybrid sources attain its maximum energy.

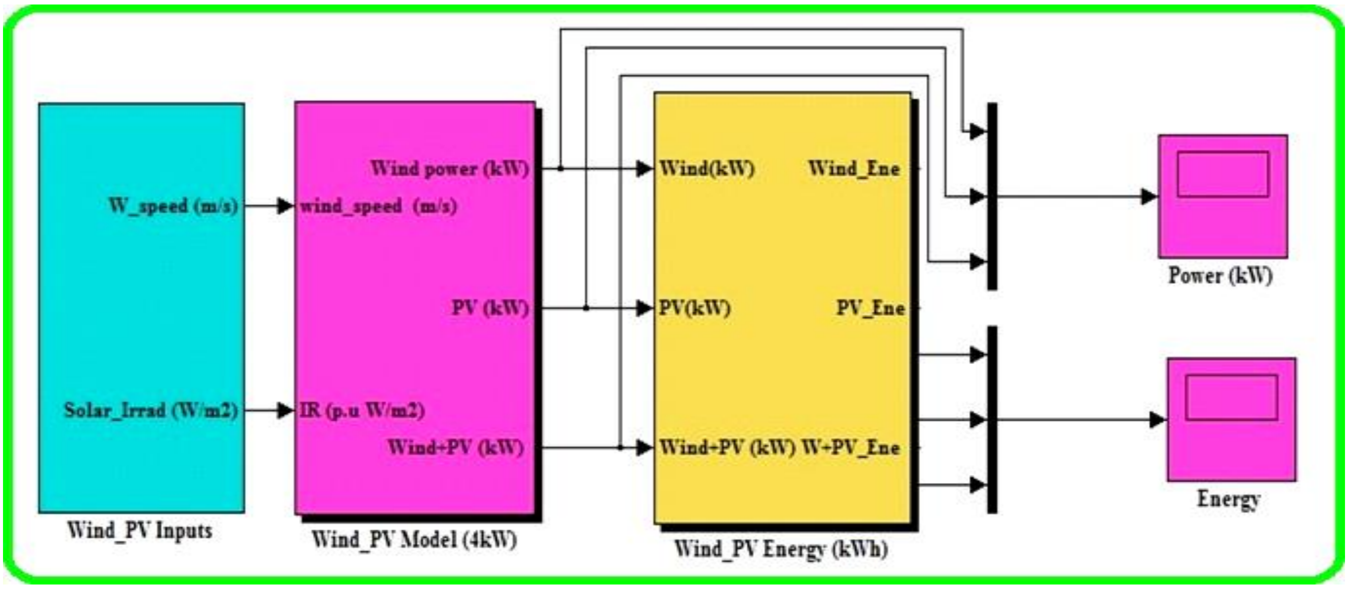

Fig. 8 Block diagram of hybrid wind-solar virtual model

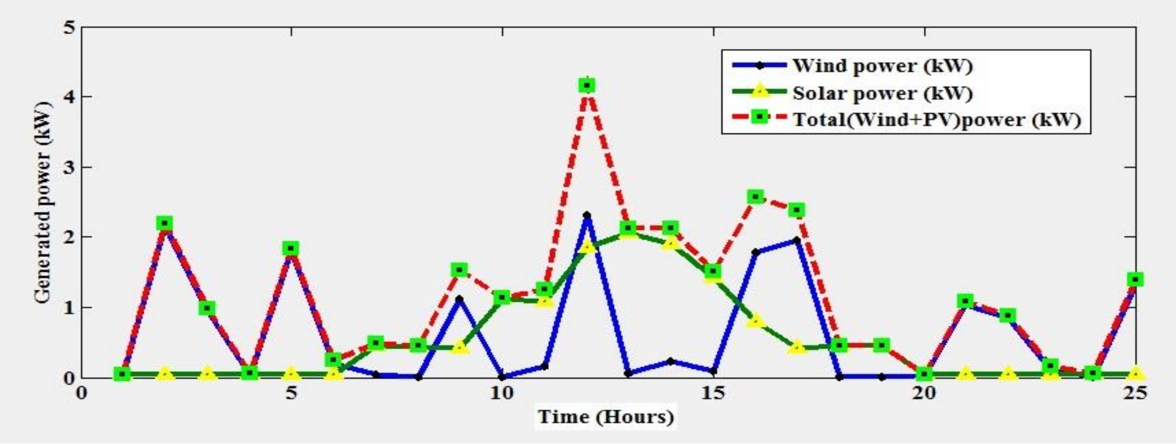

Fig.9 Power generation in hybrid virtual model

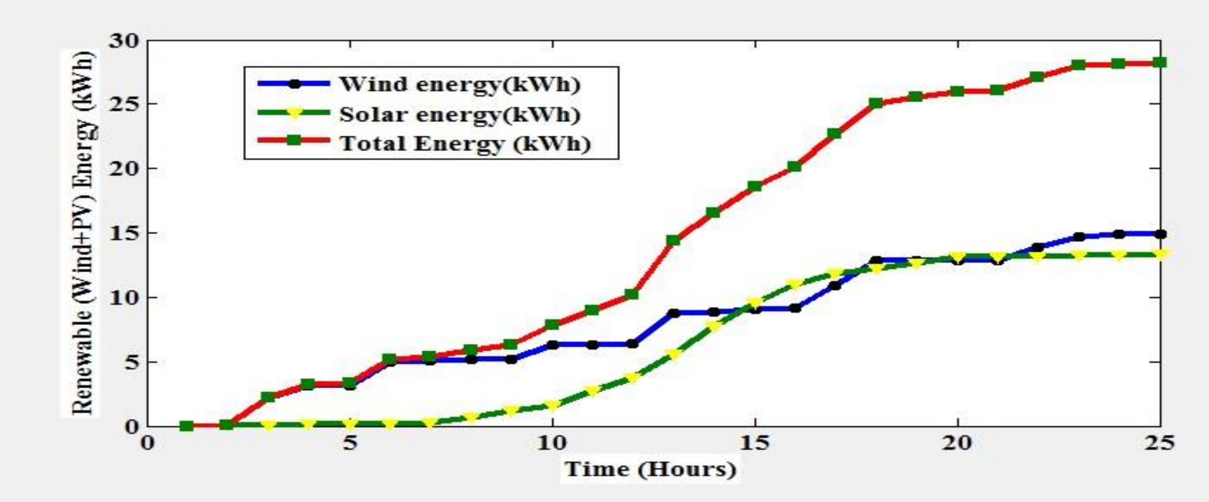

Fig.10 Energy generation in hybrid virtual model

The renewable energy generations shown in Fig.10 exhibit 13.4kWh solar energy, 14.8kWh wind energy with a total of 28.18kWh with an average of 1.17kWh energy available to store it in the battery to run hybrid air-conditioning system. The simulation also extended to study the power and energy generations available through summer and winter seasons.

This proposed location is simulated as a summer condition for 8 months and 4 months winter season in a year. This analysis considers 5-21m/s and 2-18m/s wind speed variation for summer and winter, respectively. Similarly, solar irradiation of 0.2-1.2 W/m^2 and 0.092-1.02 W/m^2 are considered for summer and winter, respectively. The summer period is simulated (245days×24h) for 5880 hours/year and the winter period for (120days×24h) for 2880 hours/year and power generation shown in Fig.10 in summer, 7126kWh wind energy and 5372kWh solar energies are generated for the input values mentioned, In summary shown in Fig.11 shows that the winter, wind-solar energy generation of 1155kWh and 2623kWh respectively yields a maximum energy generation of 3777kWh.

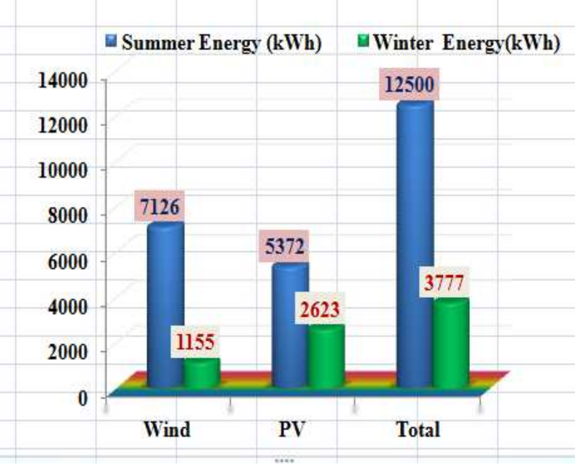

Fig.11 Hybrid wind-solar energy annual generation

Similarly, it (Fig.11) also exhibits the annual wind-solar energy generation with 57% of wind energy generated during summer in total energy generation, but it is reduced to 30.5% in the winter energy. The solar energy generates a high of 69.4% total energy generation in winter and 50.9% in summer and 49.1%. The solar with wind participation in the overall energy generation profile per annum indicates maximum energy generation of 12500kWh.

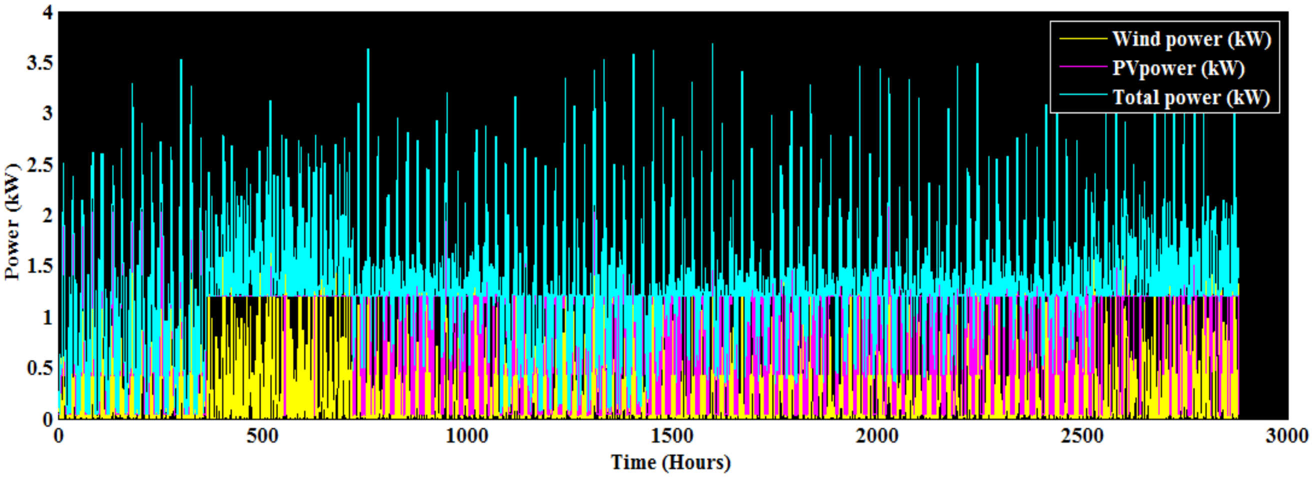

Fig. 12 Winter weather profile power generation (for 4 months in a year)

4.2 HAC Cost and energy-based analysis

As it is described in section 3.1, the total cost savings of 345USD/year optimal conditions that can significantly reduce the amortization period by about 8 to 9 years for a domestic consumer. This installed 2.2kW need not be used only for the air conditioning system it can operate other electrical appliances in the home. The total number of consumers being served in the proposed State (Roseline and Mathur 2011) as of 31.03.2018 is 28.81 million and 20 % of these total consumers accepting to generate 2kW hybrid wind-solar energy, the supply side can generate approximately 1120MW. The independence of power generation is motivated by suitable policy-making and incentives, then only the inevitable load changes can be managed by the supply grid. This paper defines this approach of consumer support on the load side as Demand Side Source Management (DSSM) because the consumer side source generation solves meet the rapid energy requirements for the next three or four decades. For the discussion on the energy efficiency of the drive system, a common 1.5kW motor capacity was taken for the discussion. The efficiency calculation describes that the proposed BLDC motor is approximately 13% to 20% more efficient than the conventional single-phase induction motor which shows that 5 Units of electricity are conserved per day. According to IEA report energy (Futur. Cool. 2018), demand for space cooling will consume nearly 40% means that this conservation of energy is a meaningful solution for this dominant electrical load across the global electricity market. Hence, replacing induction motors with efficient, reliable, stable noise-free BLDC motors is mandatory for the next generation air conditioning system. The proposed BLDC motor takes 32A at 48V and consumes a maximum power of 1584W. Even though the compression and the noise level are satisfactory for the BLDC motor, the high current 32A and low voltage design necessitates huge 6AWG conductor sizes and large MCB switches. A 220V BLDC motor is commercially available in the electricity market this current rating and the bulky switches need not be in the circuit. The hybrid energy wind-solar system proposed in this work may also be operated in the fuzzy based home autonomous mode (Azim Keshtkar and Arzanpour 2014) (Abdolazim Keshtkar 2015) with 2.2kW active power without storing energy in the batteries employing a fuzzy-based intelligent control system for the efficient use of hybrid energy to be independent of the supply grid.

5 Conclusion

This paper describes a solution through a realistically designed hybrid wind-solar air conditioning model for an inevitable problem to be instigated by the air conditioning loads. The simulation results at optimal conditions illustrate that this proposed hybrid 4kW system generating an average of 1356 kWh/month. This energy is quite useful in the dominating summer and it gives a smart solution for running air conditioning loads. At normal wind speed, the proposed lift and drag force-assisted IWT model may generate enough voltage levels to supply the air-conditioning loads. The presence of BLDC motor in the air conditioning system demonstrated the energy efficiency, smooth, reliable operation with a PWM speed controller. The hybrid air conditioning model cost 952 USD, including free energy provision looking more economical than the conventional air-conditioning for purchasing appliances alone. The proposed model is designed with many existing resources to reduce the overall project cost however the same model is prepared with the right selection of components may give a better cost-effective energy-efficient air conditioning model. This proposed HAC model also provides a solution to future demand growth due to the factor like global warming and per capita energy consumptions.

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Declaration

Author Contributions

Conceptualization, M.A.; Methodology, M.A.; Software, M.A.; Validation, V.P; Formal Analysis, V.P ; Writing Original Draft Preparation M.A. ; Review & Editing M.A.; Supervision, V.P.;

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