Micro-Hybrid Power Systems – A Feasibility Study

Arjun A. K., Athul S., Mohamed Ayub, Neethu Ramesh, and Anith Krishnan

Abstract—**One of the primary needs for socio-economic development in any nation in the world is the provision of reliable electricity supply systems with lower carbon footprint levels. The purpose of this work is the development of a Solar-Wind hybrid Power system that harnesses the renewable energies in Sun and Wind to generate electricity. The detailed measurement and analysis of the data for a period of one month is taken for conclusions in this paper. The results show that the site is abundant in renewable energy and the hybrid nature increases the reliability and reduces the dependence on one single source.**

Index Terms—**Battery, charge controller, hybrid, photovoltaic cell, power, solar, wind.**

I. Introduction

We all know that the world is facing a major threat of fast depletion of the fossil fuel reserves. Most of the present energy demand is met by fossil and nuclear power plants. A small part is met by renewable energy technologies such as the wind, solar, biomass, geothermal etc. There will soon be a time when we will face a severe fuel shortage. As per the law of conservation of energy, “Energy can neither be created, nor be destroyed, but it can only be converted from one form to another”. Most of the research now is about how to conserve the energy and how to utilize the energy in a better way. Research has also been into the development of reliable and robust systems to harness energy from non-conventional energy resources. Among them, the wind and solar power sources have experienced a remarkably rapid growth in the past 10 years. Both are pollution free sources of abundant power.

With high economic growth rates and over 17 percent of the world’s population, India is a significant consumer of energy resources. Despite the global financial crisis, India’s energy demand continues to rise. India consumes its maximum energy in Residential, commercial and agricultural purposes in comparison to China, Japan, and Russia. Kerala is one of the states in India that is blessed with renewable energy resources. Despite being a densely populated state with high consumption rate of energy, it lacks appropriate energy management policies and has started facing resource scarcity. Although there is a minimal scope of around 700MW wind energy to be tapped from our state (Kerala), we do still believe that setting up of small and reliable hybrid power generating units like this will effectively make consumers independent in meeting their own power demands. This will in turn bring down the burden on the grid.

Wind energy is the kinetic energy associated with the movement of atmospheric air. It has been used for hundreds of years for sailing, grinding grain and for irrigation. Wind energy systems convert this kinetic energy to more useful forms of power. Wind energy systems for irrigation and milling have been in use since ancient times and at the beginning of the 20th century it is being used to generate electric power. Windmills for water pumping have been installed in many countries particularly in the rural areas. Wind turbines transform the energy in the wind into mechanical power, which can then be used directly for grinding etc. or further converting to electric power to generate electricity. Wind turbines can be used singly or in clusters called ’wind farms.

Solar energy is energy from the Sun. It is renewable, inexhaustible and environmental pollution free. Solar charged battery systems provide power supply for complete 24 hours a day irrespective of bad weather. By adopting the appropriate technology for the concerned geographical location, we can extract a large amount of power from solar radiations. More over solar energy is expected to be the most promising alternate source of energy. The global search and the rise in the cost of conventional fossil fuel is making supply-demand of electricity product almost impossible especially in some remote areas. Generators which are often used as an alternative to conventional power supply systems are known to be run only during certain hours of the day, and the cost of fueling them is increasingly becoming difficult if they are to be used for commercial purposes.

There is a growing awareness that renewable energy such as photovoltaic system and Wind power have an important role to play in order to save the situation. Hybrid power system consist of a combination of renewable energy source such as wind generators, solar etc of charge batteries and provide power to meet the energy demand, considering the local geography and other details of the place of installation. These types of systems are not connected to the main utility grid. They are also used in stand-alone applications and operate independently and reliably. The best application for these type of systems are in remote places, such as rural villages, in telecommunications etc. The importance of hybrid systems has grown as they appear to be the right solution for a clean and distributed energy production. As an initial step towards the development, we shall run the street lighting around the main blocks of the college, which presently draw power from the electricity board supply lines.

Manuscript received October 13, 2012; revised December 26, 2012.

Arjun A. K., Athul S., Mohamed Ayub and Neethu Ramesh are with the Department of Electrical and Electronics Engineering, College of Engineering, Thalassery, Kerala, India – 670107.

Anith Krishnan is with the Department of Electrical and Electronics Engineering, College of Engineering, Kidangoor, Kerala, India – 686583 (e-mail: anithkrishnan@gmail.com).

DOI: 10.7763/JOCET.2013.V1.7

II. Wind Power System

Wind is the flow of atmospheric air in accordance with temperature, which carries enormous quantity of energy. The wind generator units convert wind power into electrical power. The wind passes through the propeller and producing the circumferential force and axial thrust. This circumferential force is also known as torque, which drives the generator to produce the electrical power. The wind velocity is a variable quantity, both in magnitude and in direction. This variable feature of wind turbine power generation is different from conventional fossil fuel, nuclear or hydroelectric power systems. Wind energy has become the least expensive renewable energy technology in existence. The greatest advantages of electricity generation from wind are that, it is renewable, eco-friendly and needs less maintenance. Wind is available in abundance, possibly everywhere in the world and it will not get depleted with use.

The power in the wind is directly proportional to the area of the wind turbine swept by the wind and also to the cube of the velocity of the wind. A simple expression for the power that can be harnessed from the wind is given by

$$P = \frac{1}{2}\rho A V^3 \qquad (1)$$

where ρ is the density of air and is taken as $1.225\ \text{kg/m}^3$.

A is the area of the wind turbine swept by the wind

V is the velocity of the wind.

A common factor that is used for judging the reliability of any power source is to determine its capacity factor. Capacity factor is the ratio between powers produced over time to the power that could have been produced if the generation source operated at maximum output, at 100% of the time. A conventional fossil fuel based power plant will have a larger capacity factor as it gives power continuously, unless otherwise during maintenance period. For a wind power system, it is more of a question of the availability of the wind, as the wind is random in speed and direction. Thus a wind turbine will not always work at maximum output condition.

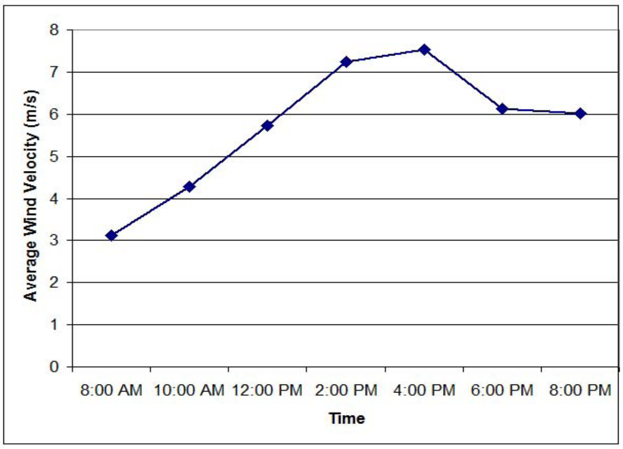

Fig. 1. Actual wind profile for 12 hours at the site on a day in the month of July 2012.

There are basically two types of wind turbine designs, based on the axis in which the turbine rotates.

A. Horizontal Axis Wind Turbine (HAWT)

B. Vertical Axis Wind Turbine (VAWT)

A. Horizontal Axis Turbine

Horizontal-axis wind turbines (HAWT) get their name from the fact that their axis of rotation is horizontal. They have the main rotor shaft and electrical generator at the top of a tower, and are pointed into the wind. The variability of wind distribution and speed brings up the requirement of a gear system connected to the rotor and the generator. The gear system enables a constant speed of rotation to the generator thus enabling constant frequency generation. Turbine blades are made in order to prevent the blades from being pushed into the tower by high winds.

B. Vertical Axis Turbine

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically as the plane of rotation is vertical. Blades are also vertical in this arrangement. The biggest advantage of VAWTs is they don't require a yaw control mechanism to be pointed into the wind. Thus these are useful at sites where wind direction is random or at places where there is presence of large obstacles like trees, houses etc. Also VAWTs don't require a tower structure and can be placed nearby a ground enabling access to electrical components. Some drawbacks are the low efficiency of wind production and the fact that large drag is created for rotating the blades in a vertical axis.

III. Project Site

The details of the project site are given below.

Location : College of Engineering, Thalassery

Latitude : 11° 46' 59.33"

Longitude : 75° 30' 53.27"

Towards East : Kannavam hills

Towards West : Thalassery town

Towards North : Anjarakandy-Mambaram river

Towards South : Arabian Sea

IV. Solar Power System

Solar energy is the energy produced by sun through the process of thermonuclear fusion. The process converts about 650 Mega tons of hydrogen to helium per second. The process creates heat and electromagnetic radiations (radiation is the process of heat transfer from source to the target directly). The heat remains in sun and is instrumental in maintaining the thermonuclear reaction. The electromagnetic radiation stream's out in all directions and some energy is lost by

Scattering

Absorption

Cloud cover

Reflection

Climate

The solar energy irradiation at the site is a major factor in selection of the implementation of the project. The solar cells which are also called as photovoltaic (PV) cells are p-n junction diodes with large areas and the junction positioned close to the top surface. The cell converts sun light into direct current electricity. Unlike the dynamic wind turbines, the PV installations is static, does not need strong tall towers, produces no vibration or noise, and needs no cooling. Because much of the current PV technology uses crystalline semiconductor material similar to integrated circuit chips, the production costs have been high. The price of the cell has been coming down over the years. This high price is also compensated by the government by giving subsidies to the customers. This has helped in increasing the popularity of solar cells for small scale and large scale uses.

A. Components of a Solar Power System

The following are the major components required to implement a solar powered system.

1. Collector unit (Photovoltaic cells)
2. Storage unit (battery bank)

The collector unit collects the radiations that falls on it and converts a fraction into the required form of energy (either electricity and heat or heat alone).

The storage unit is connected to the system because of the variable nature of solar energy. At night and during the cloudy days, the energy extracted will be comparatively small. The storage unit (battery bank) holds the excess energy produced during the period of maximum productivity and supplies the backup power whenever required.

B. Maximum power point tracking (MPPT)

It's a technique that is used to track maximum amount of energy falling on solar panels. In order to achieve this we make use of an MPPT algorithm together with a sun-tracker. Sun trackers are of two types. Single axis and two axes sun trackers. In a two axes system both azimuthal and tilt angles are varied whereas in a single axes system tilt angle is fixed and azimuthal angle is varied.

V. Hybrid Power System

As the wind does not blow throughout the day and the sun does not shine for the entire day, using a single source will not be a suitable choice. A hybrid arrangement of combining the power harnessed from both the wind and the sun and stored in a battery can be a much more reliable and realistic power source. The load can still be powered using the stored energy in the batteries even when there is no sun or wind. Hybrid systems are usually built for design of systems with lowest possible cost and also with maximum reliability. The high cost of solar PV cells makes it less competent for larger capacity designs. This is where the wind turbine comes into the picture, the main feature being its cheap cost as compared to the PV cells.

Battery system is needed to store solar and wind energy produced during the day time. During night time, the presence of wind is an added advantage, which increases the reliability of the system. In the monsoon seasons, the effect of sun is less at the site and thus it is apt to use a hybrid wind solar system. In addition to the technical considerations, cost benefit is a factor that has to be incorporated into the process of optimizing a hybrid energy system. In general, the use of wind energy is cheaper than that of solar energy. The solar-wind hybrid system is more cost-effective and reliable when wind is taken as a source. Fig. 2 shows the block diagram of the hybrid system.

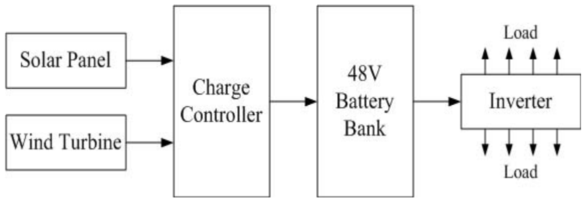

Fig. 2. Block diagram of Wind-Solar hybrid power system.

A. Hybrid System at the Campus

At the site (our college campus), the wind energy component will make a more significant contribution in the hybrid system than solar energy. As the site is located on the top of the hill which is nearly at a distance of 5 Km from Arabian sea. The site is rich with the resource wind. Moreover being located at the top op of hill (Kundoormala), the site is rich in direct solar radiations without any obstructions. At the site, we had obtained a maximum of 265 Klux of solar radiation and a maximum of 14.59 m/s of wind. From these available energy resources, the system would be self sufficient to run all the street lights of campus during night periods (which can reduce the consumption of energy at peak load time).

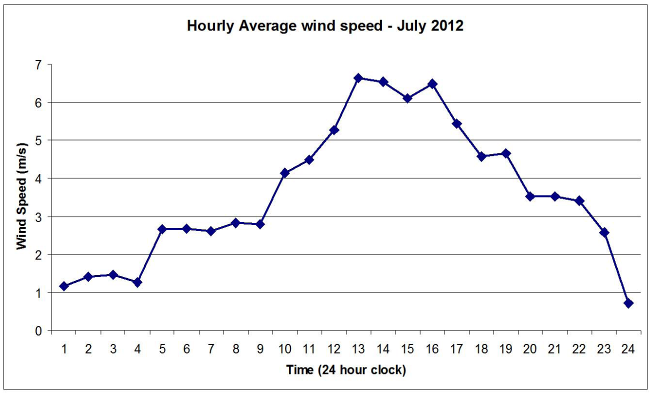

Fig. 3. Hourly average wind speed during the July 2012.

The average wind speed at the project site during the month on July 2012 is shown in figure 3. From the 24 hour wind profile data, it is clear that the wind speed during night time is not sufficient enough to generate electric power. Since this data was taken for the month on July 2012, a month during the rainy season, we cannot be sure that this will be the same throughout the year. For a decent conclusion, we need to get the wind profile for at least 2 or 3 years.

VI. Design Considerations

Since the wind velocity is not so high, but sufficient enough to generate electric power, the first and foremost step is to increase the swept area. A preferred area is $3.5m^2$. With this, the power generated by considering the Betz limit is shown in Figure 4.

Taking the cut-in speed of the turbine to be 3.5m/s, it is evident from the Figure 4 that a total power of over 1kW (assuming generator efficiency to be at least 90%) can be generated from the wind during day time. Since wind energy can be generated cheaply as compared to solar energy, we shall reduce the capacity of the solar panel connected to the circuit. The Sun's radiation reaching the project site is a variable quantity. A typical incident power per unit area versus the time of the day is shown in Fig. 3.4. The design rating of a 1kW panel is shown in Figure 5.

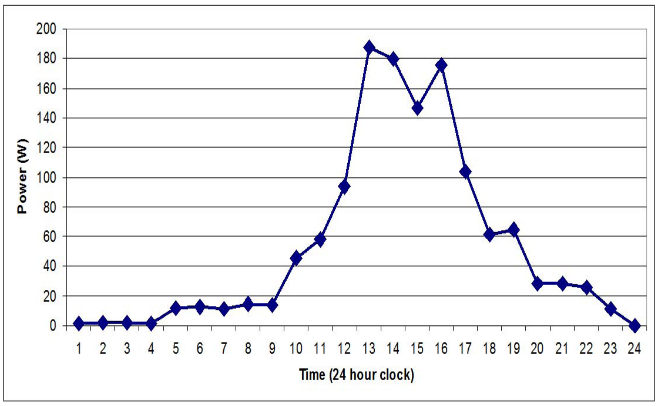

Fig. 4. Hourly average wind power harnessed during the July 2012.

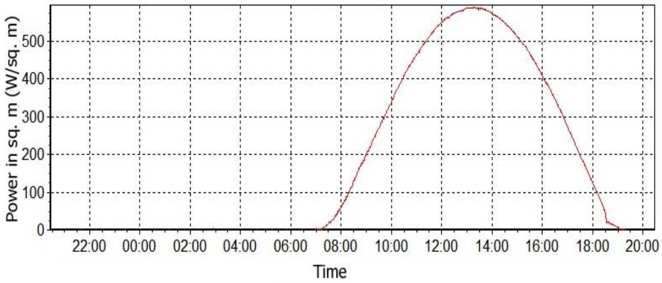

Fig. 5. Availability of power per unit area during a day.

As seen in Figure 5, it is clear that the Earth receives the maximum power from the Sun in between 11:00 a.m. and 03:00 p.m. The battery bank designed is 48V, 200Ah. We had also considered a DOD of 50%. Thus the total energy required to charge a battery that is 50% drained is 4800Wh. For the simplicity of the design, let us assume that the Sun's energy is available for at least 10 hours a day. Thus, ideally speaking a 480W rated solar panel can produce 4800Wh in 10 hours. But in the practical case, this not happening due to the variation of availability of Sun's radiation (see Fig. 5). To be on the safer side of the design a panel rating of 175% than the ideal rating is chosen. Thus the rating of the panel is 480×1.75 = 840W. The better option being a 1kWpanel, considering the converter efficiency to be 90%.

This designed rating was suitable only to charge a half drained battery to full charge. With the addition of the wind generator to this system, the power system has become more reliable as the power is harnessed from two different sources. Considering the additional availability of the power, the 1kW panel can be replaced with a 0.5kW panel for the same battery bank.

The energy stored in the batteries can then be used directly to power DC loads or it can be inverted to power AC loads. The batteries recommended for renewable energy systems are deep cycle batteries. To ensure enough reserve capacity to provide the electricity required, the battery bank size has to be chosen properly. Because of the various conditions affecting battery bank sizing, this has to be done carefully. Before tackling the calculations, the following pieces of information are to be identified:

1. Watt hours of electricity usage per day
2. Number of days of autonomy
3. Depth of Discharge limit
4. Ambient temperature of battery bank

A. Electricity Usage

Let us take the total connected load to be driven as 8 nos. of CFLs each rated at 23W.Total load = 8×23 = 184W. Since we propose to drive the lights during night time, it should give us a continuous running time of 10 hours per day on an average. Thus, Total energy requirement per day, Er = 184×10 = 1840Wh.

B. Days of Autonomy (DA)

Days of autonomy is number of days of backup required by the system. In other words, if you are unable to charge your batteries by any means, and you still need to draw power, you must provide this additional storage by increasing the size of your battery bank. For the purpose of sample calculation, let the days of autonomy be 2.

C. Temperature Compensation (TC)

A typical temperature compensation value is 1.1, considering the annual temperature variation at the project site.

D. Depth of Discharge (DOD)

Another factor to consider is the planned Depth of Discharge (DOD) of the battery bank. Flooded lead acid batteries (FLA), sealed AGM batteries and sealed gel batteries are all rated in terms of charge cycles. A single cycle takes a battery from its fully charged state, through discharge (use), then back to full charge via recharging. The depth of discharge is the limit of energy withdrawal to which the battery (or battery bank) is subjected to DOD is expressed as a percent of total capacity. The further a battery is discharged, the fewer cycles that the battery will be capable of completing. Simply stated, deeper discharge shortens battery life. This gives an idea about the practical limit of discharge of a battery (see Fig. 6).

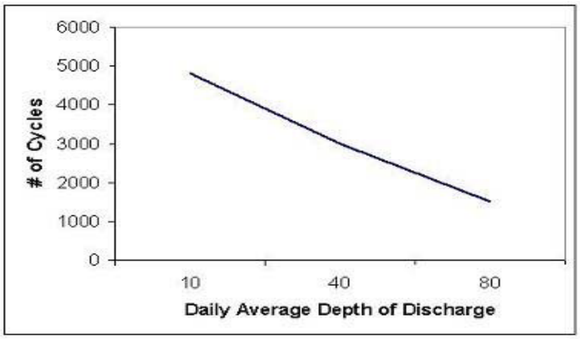

Fig. 6. Relation between the battery life and the depth of discharge

E. System Voltage

The usual system voltages (on the DC bus) are 12V, 24V or 48V. It is always better to go for higher system voltages to reduce the losses and as such the choice is definitely 48V. Thus the choice of battery bank voltage is 48V.

F. Battery Bank

The total consumption in Ah is given by

$$Ahc = \frac{Er}{Battterybankvoltage} = \frac{1840}{48} = 38.33Ah$$

The battery bank capacity is given by

$$Aha = \frac{Ahc \times TC \times DA \times DM}{DOD} = \frac{38.33 \times 1.1 \times 2 \times 1.1}{0.5} = 185.53Ah$$

A standard battery rating available confirming to the design above is 12V, 100Ah. In order to meet the voltage rating, 4 such batteries are connected in series to get the voltage rating of 48V, and two such arrangements are connected in parallel to get a total current rating of 200Ah (see Fig. 7), which is above the required design value.

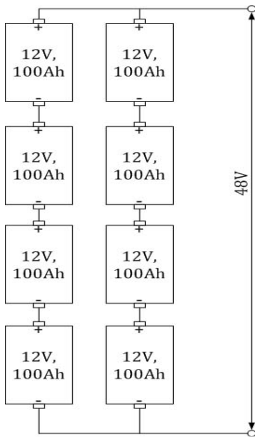

Fig. 7. Battery bank connection

VII. Conclusions and Future Scope

The inclusion of an additional power source (wind power) has brought down the rating of the solar panel. This has helped in the dependence of the system on a single power source and has increased the reliability. Systems of much higher capacity can be built by extending (scaling) this design. Small standalone systems like these along the coastal belt of Kerala can help in taking a considerable amount of load off the grid. This will help our state, Kerala to use the excess power for other activities. The major hurdle in implementing projects like these is to get the people understand the benefits of such projects to them, as well as the country.

Since sufficient power is available from the wind, a standalone direct power inverter system which drives a load without using intermittent battery bank can also be a future work. Although such systems does exist now using solar energy, we could not find much work done using wind energy. The identification and use of other renewable sources of energy to improve the reliability and dependence on a single power source is also under consideration. The idea that has the most priority is the conversion of heat absorbed by concrete buildings (or structures) into electricity. This can in a way help to generate electricity and also reduce the burden of air conditioners as they will be running on lighter loads.

Acknowledgment

The authors would like to thank the Principal, College of Engineering, Thalassery for providing facilities that were required for the preparation of the work. The authors would also like to thank Mr. Bijumohan K. M., Assistant Executive Engineer, KSEB for the support and encouragement given on behalf of KSEB Engineers Association.

References

[1] Zhao K. and Sun X., "Cascaded wind power generation system with variable speed constant frequency," International Conference on Mechanical Engineering and Automation, Advances Biomedical Engineering, 2012.

[2] M. Muralikrishna and V. lakshminarayana, "Hybrid (solar and wind) energy systems for rural electrification," *ARPN Jounral of Engineering and Applied Sciences*, vol. 3, no. 5, pp. 50-58, October 2008.

[3] ATA, "Solar panel buyers guide," *ReNew: technology for a sustainable future*, Issue 101, pp. 48-54, October-December 2007.

[4] E. Koutroulis and K. Kalaitzakis, "Design of a maximum power tracking system for wind-energy-conversion applications," *IEEE Transactions on Industrial Electronics*, vol. 53, no. 2, pp. 486-494, April 2006.

[5] R. Pecen, Salim MD, and M. Timmerman, "Hybrid solar-wind power generation system as an instructional resource for industrial technology students," *Journal of Industrial Technology*, vol.16, no. 3, pp. 1-7, 2000.

[6] M. R. Patel, *Wind and Solar Power Systems*, CRC Press.

[7] B. Samantaray and K. Patnaik, "A study of wind energy potential in India," Thesis Report, NIT, Rourkela, 2010.

[8] Btek Renewable Energy. [Online]. Available: http://www.btekenergy.com/documents/215.html

[9] Battery and Energy Technologies. [Online]. Available: http://www.mpoweruk.com/leadacid.htm

Arjun A. K. was born in Kannur (Kerala, India) in January 1993. He is an under graduate student in Electrical and Electronics Engineering at College of Engineering, Thalassery (Kerala, India) under Co-operative Academy of Professional Education and affiliated to Cochin University of Science and Technology. His areas of interest are renewable energy technologies, sustainable development and power systems.

Athul S. was born in Calicut (Kerala, India) in May 1993. He is an under graduate student in Electrical and Electronics Engineering at College of Engineering, Thalassery (Kerala, India) under Co-operative Academy of Professional Education and affiliated to Cochin University of Science and Technology. He is interested in electrical science and renewable energy sources.

Neethu Ramesh The author was born in Kannur, Kerala. She is an under graduate student in Electrical and Electronics Engineering at College Of Engineering Thalassery (Kerala, India) under Co-operative Academy of Professional Education and affiliated to Cochin University of Science and Technology. She is a recipient of Central Sector Scholarship (2008-2011) for academic excellence. She won 4^{th} place with 'A' grade for her topic 'Energy from Wind' in the Kerala State Social Science Fair 2008 at Kerala. She has also won accolades in various district level and state level Science Exhibitions. Her areas of interest are wind energy conversion systems, solar photovoltaics and power systems.

Mohamed Ayub was born in Sharjah (UAE) in July 1992. He is an under graduate student in Electrical and Electronics Engineering at College of Engineering, Thalassery (Kerala, India) under Co-operative Academy of Professional Education and affiliated to Cochin University of Science and Technology. His areas of interest are renewable energy technologies and sustainable development.

Anith Krishnan was born in Ernakulam, a major district in the state of Kerala, India. He completed his B.Tech. in Electrical and Electronics Engineering from School of Engineering, Cochin University of Science and Technology, India in 2007. He received his M.Tech. in Guidance and Navigational Control from College of Engineering, Trivandrum, Kerala, India in 2009. His major areas of interest are energy conservation and management, sustainable development, renewable energy, guidance and control of aerospace vehicles etc.

He is now working as Assistant Professor in the Department of Electrical and Electronics Engineering, College of Engineering Kidangoor, Kerala under CAPE (Cooperative Academy of Professional Education). He has presented papers on guidance and control of reusable entry vehicles in a national and an international conference.