Research, Design, Development & Demonstration (RD^3) of a Wind Solar Hybrid (WiSH) System

Manabendra M. De, K Jayaprakash Reddy, L Srikanth, S Jayasankar, Kanaka Muthu, T H Samiullah, G N Dayananda

Centre for Societal Missions & Special Technologies (CSMST),
National Aerospace Laboratories (NAL),
Council of Scientific and Industrial Research (CSIR), Bangalore 560 017

E-mail: manav@nal.res.in, prakashk@nal.res.in, skanth@nal.res.in, jsankar@nal.res.in, kanaka@nal.res.in, sami@nal.res.in dayanand@nal.res.in

Abstract

Wind energy related activities had been initiated at NAL by the first director Dr P Nilakantan in 1959 and later valuable contributions were made through the wind resource assessment leading to the discovery of major windy sites in the southern India during the 70's energy crisis. In the past few years, NAL had ventured into the design and development of wind turbines in order to create the indigenous technology base within the country. With its rich multi-disciplinary experience in the niche area of design of aircraft wings and helicopter rotors, an indigenous development of a 500 W wind turbine rotor for low wind conditions was taken up and successfully completed.

However, to address the energy needs of remote areas in the country, it was realized that a hybrid concept tapping the wind and solar resources would be ideal and hence the development of a Wind-Solar Hybrid (WiSH) system was initiated at CSMST, NAL. This developmental work was multi-disciplinary in nature involving domains of aerodynamics, structural dynamics, electrical & controls and composite fabrication technology. The challenges of integrating the two devices (wind turbine and the solar PV panels) were addressed and the necessary hardware was developed with support from the local vendors. Yet another notable aspect of the hybrid system development was that under a PPP model, the industrial partner M/s. Aparna Renewable Energy Sources (P) Ltd. (ARES), Bengaluru, was involved in this effort right from day one, to facilitate the post development production and marketing of the product.

The present paper highlights the key challenges in Research, Design, Development and Demonstration (RD^3) of the WiSH system. It elucidates how NAL translated high end aerospace technologies into applications in the renewable energy sector & designed an India-specific low wind regime wind turbine, hybridized it with the Solar PV panels and demonstrated the WiSH system along with ARES – a local MSME.

***(Keywords:** Wind Solar Hybrid (WiSH) system, Rotor Aerodynamics, Structural Dynamics, Carbon Fibre Composite, Charge controller, Public Private Partnership, CSIR-NAL)*

1. Introduction

Renewable energy technologies are ideally suited for distributed applications. They have substantial potential to provide a reliable and secure energy supply as an alternative to grid extension or as a supplement to unreliable grid power. Over 400 million people in India, including 47.5 % of those living in India's rural areas, still have no access to electricity [1]. Because of the remoteness of much of India's un-electrified rural area, renewable energy can offer an economically viable means of providing access to clean energy for the rural populace. One such technology that can be used in villages and rural areas as decentralized systems is the renewable energy source based Hybrid systems. They have been found useful even in urban and semi urban areas to conserve the use of electricity generated from fossil fuels. Ministry of New & Renewable Energy, Govt. of India has been emphasizing on R&D in this field by encouraging Academic institutes, National Laboratories and MSMEs to work as a consortium and developing home grown technologies.

Realizing the dire need to develop a rugged and low cost indigenous wind solar hybridized green technology, NAL embarked on Research, Design, Development and Demonstration (RD^3) of a 500 W + 500 W Wind Solar Hybrid (WiSH) system along with M/s. ARES.

2. RD^3 of NAL's WiSH system

The WiSH system was developed in a phased manner wherein, first the 500 W Wind turbine was designed and developed. Subsequently, it was hybridized with Solar PV panels. During the course of project execution, the team had to address several challenges. These are described in this paper.

2.1 Development of the 500 W Wind turbine:

The rich in-house experience in the multi-disciplinary areas like aerodynamics, structural dynamics, electrical & controls and composite fabrication technology have been utilised to evolve the design of small wind turbine rotor with enhanced energy harvesting features.

2.1.1 Rotor design methodology :

NAL has ventured into development of wind turbines suited to Indian low wind regimes (figure 1).

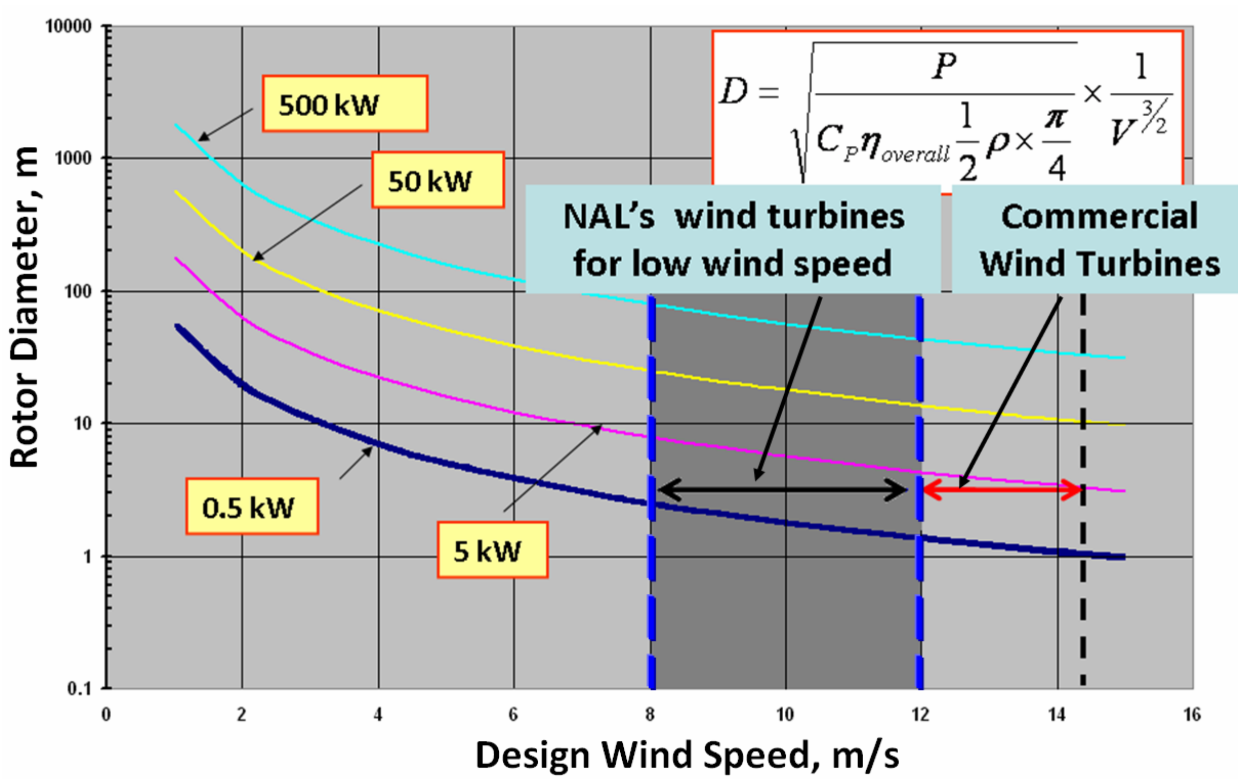


Figure 1. Operating range of Wind turbine

The rotor design methodology that has been evolved includes design, analysis, manufacturing and testing (figure 2).

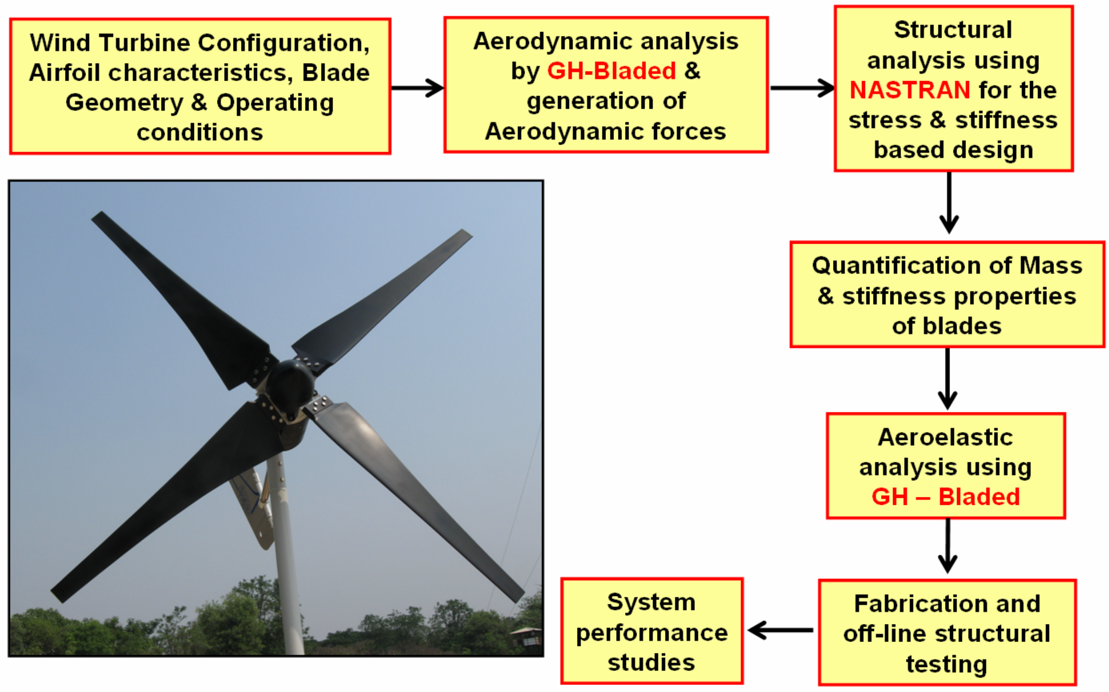


Figure 2. Design methodology for the 500 W Wind turbine

2.1.2 Aerodynamic design & analysis

Careful choice of aerodynamic profiles of the rotor blade are the key requirements of ensuring low cut in and better energy yield from the turbine. This was addressed by carefully studying the performance of airfoils at low Reynolds number of the order of 10^5, which is the operating regime of Small wind turbines. About 14 airfoils were considered. Individual evaluation of each one of them was done so as to assess the performance of the wind turbine in terms of the power curve. Based on the requirement of low cut in, optimal energy generation in low wind condition and smooth aerodynamic stalling, NACA 4412 profile was chosen. Blade shape was subsequently designed for a 3 bladed rotor configuration. Comparative plot of theoretical power curves of the wind turbine, computed using GH-Bladed software is shown in figure 3. In addition, a 4 bladed rotor was also part of the study.

GH-Bladed is industry standard software for design and analysis of horizontal axis wind turbines. It is a design tool that has been validated against measured data from a wide range of turbines. It enables the users to conduct a full range of performance prediction and loading calculations. With a Windows-based user interface, it supports calculations of combined wind and wave loading, with full aeroelastic and hydroelastic modelling. It has been used across the globe for the calculation of wind turbine loads for design and certification [2].

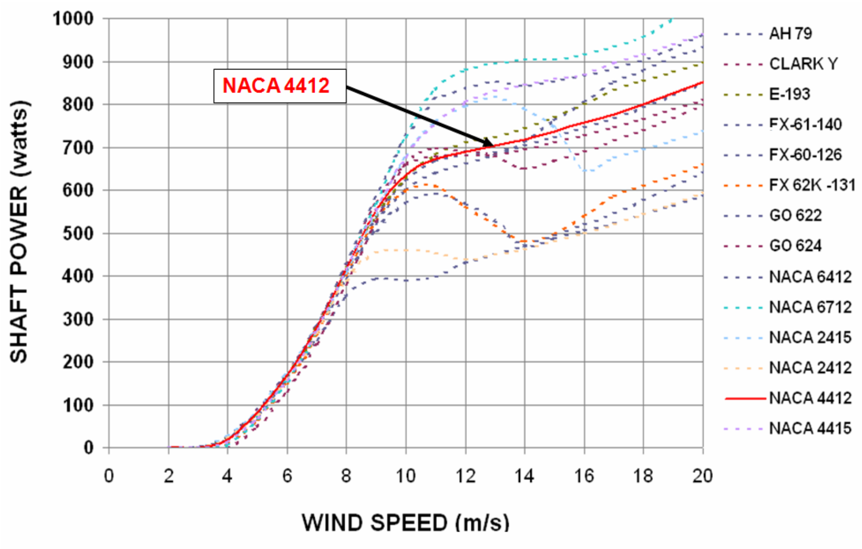


Figure 3. Comparative Theoretical Power Curves of the 500 W Wind turbine

Next, the load spectrums were theoretically computed using GH-Bladed software for structural design. A detailed structural design and analysis of CFRP blades was taken up.

2.1.3 Structural Design & Analysis

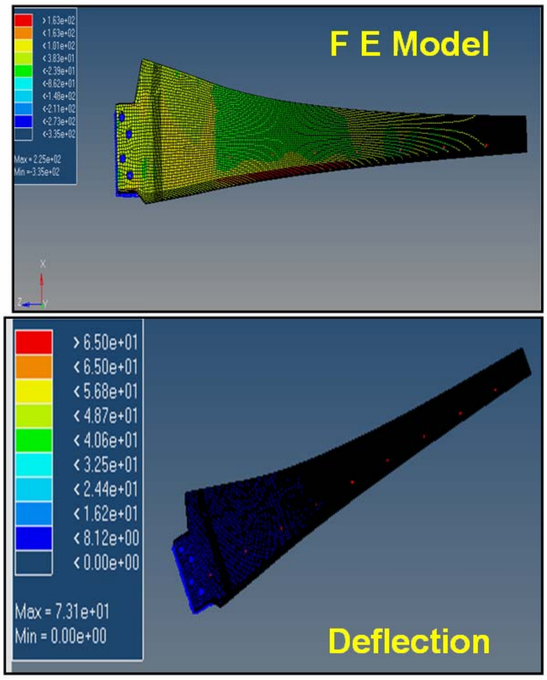
Conventionally the blades are made of glass composites (GFRP) that leave behind large ecological footprints. In this context, the carbon fibre composite (CFRP) was chosen as the blade material. The CFRP offered a light weight blade due to its inherent higher specific stiffness and strength properties on one hand, while being amenable to a relatively eco-friendly disposal as compared to GFRP on the other. With its decades of experience, NAL tuned the in-house established Aerospace grade composite materials technology for wind turbine application to cater to the need of a light weight material. This ensured less rotor inertia and low the cut-in. Finite Element analysis was carried out using the commercially available codes such as HyperMesh & Nastran for optimization of the composite layup scheme, and henceforth, the blade weight for the defined design and off-design loads. FE analysis results are shown in figure 4(a). The lay up sequence and ply drops to resist the in-plane and out-of-plane loadings were judiciously arrived at after a thorough FE analysis. The required design data on CFRP was generated in-house. A single CFRP blade weighs about 600 grams and further weight optimization exercise is being pursued.

2.1.4 Aeroelastic analysis using GH-Bladed :

After the structural design and analysis of the rotor blade is completed, the sectional stiffness (lead lag and flapwise) and mass properties (mass/unit length) are quantified from the FE model. These properties are input to GH-Bladed and aero-elastic analysis is carried out. This analysis gives the effect of flexing of the blades on the power curve. However, in case of the small wind turbine, the blades were found to be adequately stiff and did not need any further aero-elastic tailoring.

2.1.5 Fabrication of the blades

The blades were fabricated with the wet lay-up technique. Composite tools with modular features were specially developed for this purpose to facilitate incorporation of modifications in the future with ease and less time. Blades were developed as a sandwich structures. Polyurethane foam (PUF) core was casted into the required shape of the inner contour of the blade and moulded in-situ with the carbon fibre reinforcement, thereby imparting rigidity to the blade shell. The quality check on this PUF core carbon epoxy blade was carried out using a cost effective tap test non-destructive technique. Master, mould and the final CFRP components are shown in figure 4(b).



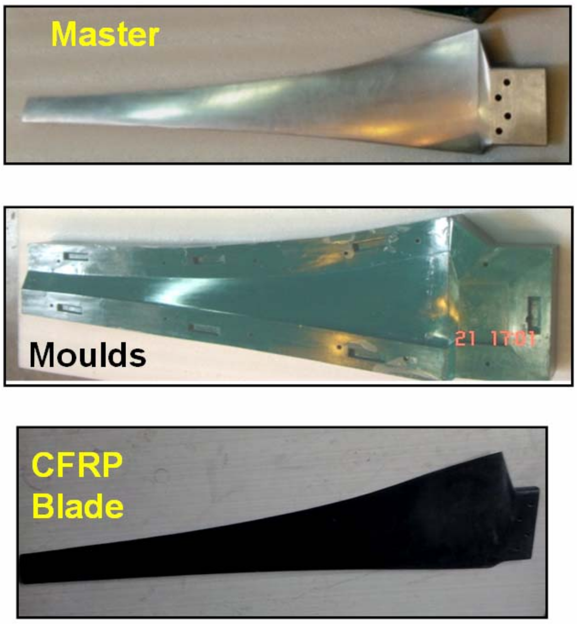


Figure 4(a) Structural Analysis Figure 4(b) Blade Fabrication

2.1.6 Off-line structural tests :

Before the system performance studies, the off-line static displacement test of the blades was conducted to ensure that they meet the stiffness requirements. Spin test of the entire rotor was carried out to ensure that the system is stable under dynamic conditions. Customized test rigs were designed, developed, fabricated and integrated and the tests were carried out. The static deflection test and spin test setup are shown in the figure 5(a) & 5(b) respectively.

Figure 5(a) Blade under static deflection test Figure 5(b) Rotor undergoing Spin Test

2.1.6 System performance studies:

After ensuring the structural integrity and dynamic stability of the blades/rotors, field trials were carried out. There were challenges of mounting the entire system over the Wind turbine Mobile test facility to carry out the Tow testing at HAL Airstrip, Bengaluru. To address this issue, turbine specific fixtures were made and the tow tests, as shown in figure 6(a) were carried out. Field trials were also conducted out at Sangeeth Wind Farm, Kethanur, Tamil Nadu, as shown in figure 6(b).

Figure 6(a) Tow Testing at HAL Airstrip, Bengaluru

Figure 6(b) Field Trials at Kethanur, Tamil Nadu

Quite often, it so happens that the entire operating regime of the wind turbine is not covered during field trials. Availability of large wind tunnel to accommodate the rotating wind turbine and the blockage effects render the tunnel tests unsuitable for evaluating the performance of a wind turbine. Hence tow testing becomes important as a range of wind speeds can be simulated to study the performance of the wind turbine. The wind turbine is mounted over the top of the Mobile Test Van and is driven on an air strip / long runway at desired speeds. Instrumentation is housed inside the van to enable the acquisition of turbine performance for the entire operating range, irrespective of the availability of the natural wind. Results of the tow testing for a commercial wind turbine (imported), NAL turbine I and NAL turbine II are shows in figure 7.

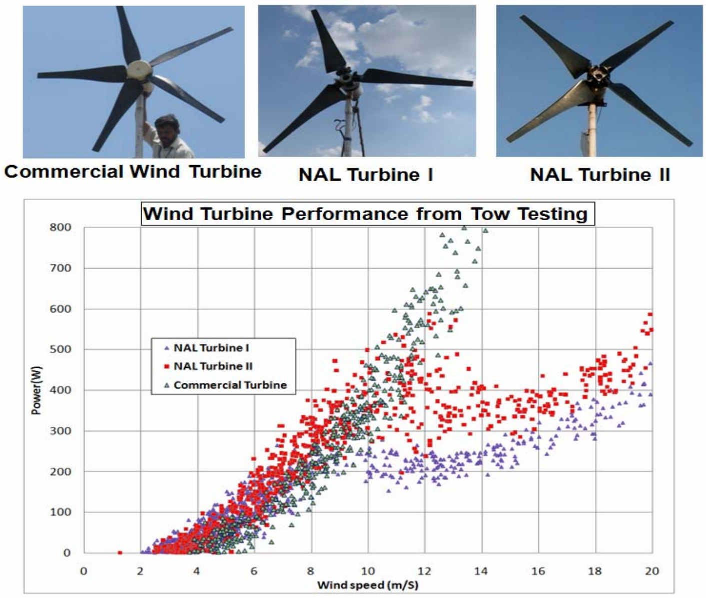


Figure 7 Wind turbine performance from Tow Testing

2.2 Development of the 500 W + 500 W Wind Solar Hybrid (WiSH) System

After the realization of an India specific Swadeshi Wind turbine, the next task was to hybridize it with solar PV module and realize the WiSH system. Following were the major issues:-

2.2.1 Arriving at the system configuration :

The first task was to evolve the configuration of the entire hybrid system and arrive at the specifications of the various components. This task was met by the Scientists from CSMST, in consultation with the technical staff of ARES as well as the local vendors, who were, at this stage, identified for supply of the COTS items. Based on the assessment of the group, the configuration was finalized for realization. The overall system configuration is shown in figure 8.

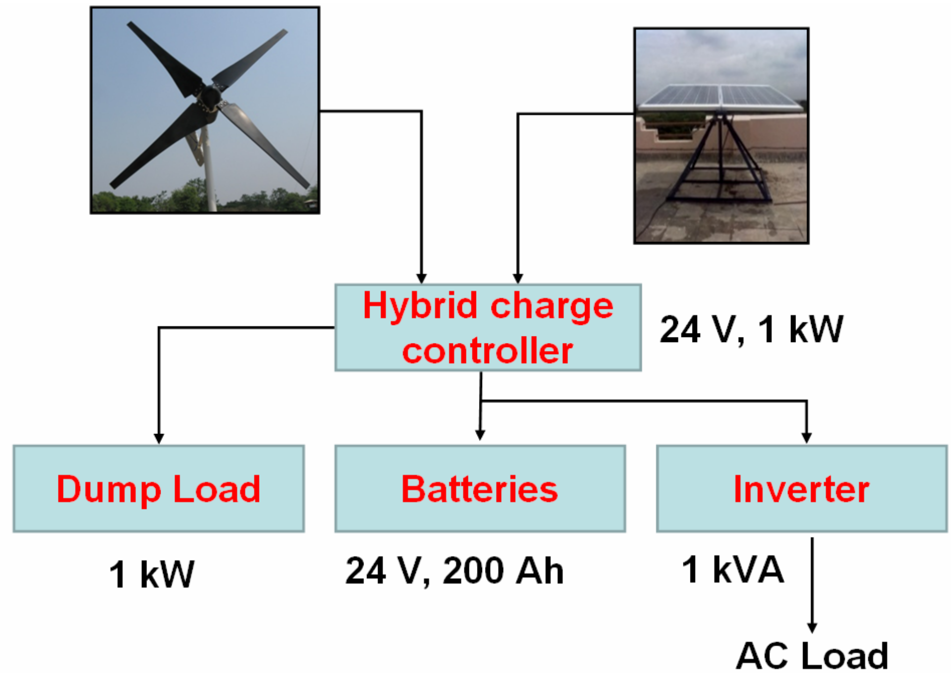


Figure 8 WiSH System configuration

2.2.2 System Integration and Development of Hybrid charge controller cum Inverter:

Once the system configuration was arrived at, the integration of the system was the next task. A rigorous study of the various methods of integrating the two sources of energy viz. wind turbine and solar PV panel was carried out. The local vendors, who were consulted for supplying the controller, were involved in exploring various cost effective options of system integration. Based on several rounds of technical assessments of various options, a custom built charge controller was finalized.

Following are the special features of Hybrid charge controller cum Inverter.

1. The charge controllers for wind, solar sources and the Inverter module are integrated in a single enclosure, reducing the number of components.
2. A stop switch is provided for wind turbine to allow the users to stop the turbine for any maintenance works.
3. When the battery is full, it diverts the wind power to dump load and puts the solar source in trickle charge mode
4. When battery is completely discharged the inverter gets switched off to prevent over discharge of battery and it gets switched on automatically when battery is charged.

The Major modules of WiSH system are shown in figure 9.

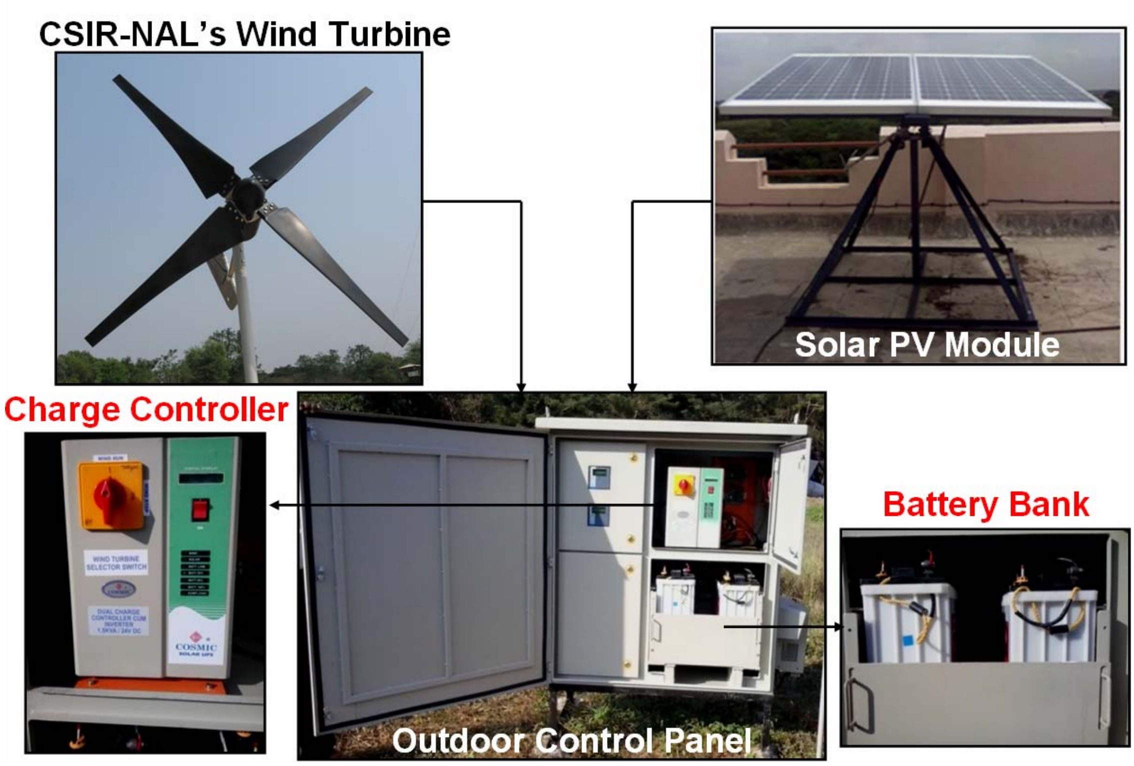


Figure 9 Major modules of the WiSH System

Once the system was integrated, the next task was to test the system in real world conditions. This task had its own issues and challenges. There were options of installing the WiSH system over the top of a building or to assess the performance in the field. The team decided to pursue both options.

2.2.3 Testing the System (over building and in the field):

After all the components were made / procured, the next task was to integrate the system and check its performance in real life conditions. It was primarily envisaged to install it in the Renewable Energy Farm, opposite the Smart Structures Building (SSB) at NAL, Kodihalli campus. At the same time, we decided to assess the system performance over the top of a building, which would represent a typical urban environment. For trials at Renewable Energy Farm, a 30 m met-mast was erected to monitor the wind pattern in the farm. In parallel, arrangements were made over the terrace of the Smart Structures Building, for carrying out the assessment of the WiSH system over the SSB, in parallel. Special anchoring arrangements were made over SSB terrace to secure the wind turbine in the right position. Associated sub-systems were assembled and field trials commenced from April, 2013. Figure 10 shows both the WiSH systems, under trial, at Renewable Energy Farm and over the SSB. Performance of the WiSH system, observed during these limited trials, is encouraging.

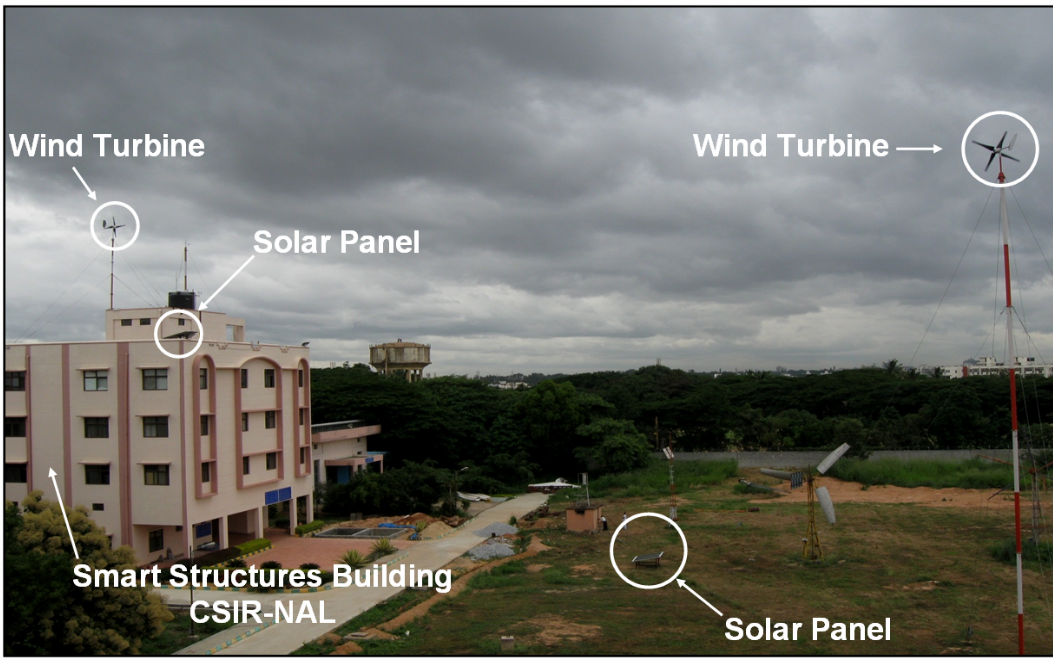


Figure 10 WiSH System under field trials

3. Involvement of Industrial partner, ARES in the RD[3]

NAL designed and developed 500 W wind turbine rotor, which had better performance vis-a-vis its foreign counterpart. Improvements were in terms of low cut-in wind speed and optimal performance in low wind regimes. ARES, our industrial partner, participated in this developmental activity by supplying suitable Permanent Magnet Generator (PMG) for the experimental prototypes and testing in the field. Once the turbine was developed, ARES supplied a set of Solar panels (2 Nos. X 250 W solar PV panels) for hybridizing them with CSIR-NAL's wind turbine. Technical personnel of ARES were stationed at CSIR-NAL and were involved in integration and testing of the 500 W + 500 W WiSH system. ARES is also involved in NAL's efforts to develop interface electronics and Maximum Power Point Tracking (MPPT) Module. ARES, in turn, had networked with other local MSMEs for components like Solar Panels, Outdoor Kiosk and Charge controller. The entire networking is shown in Figure 11.

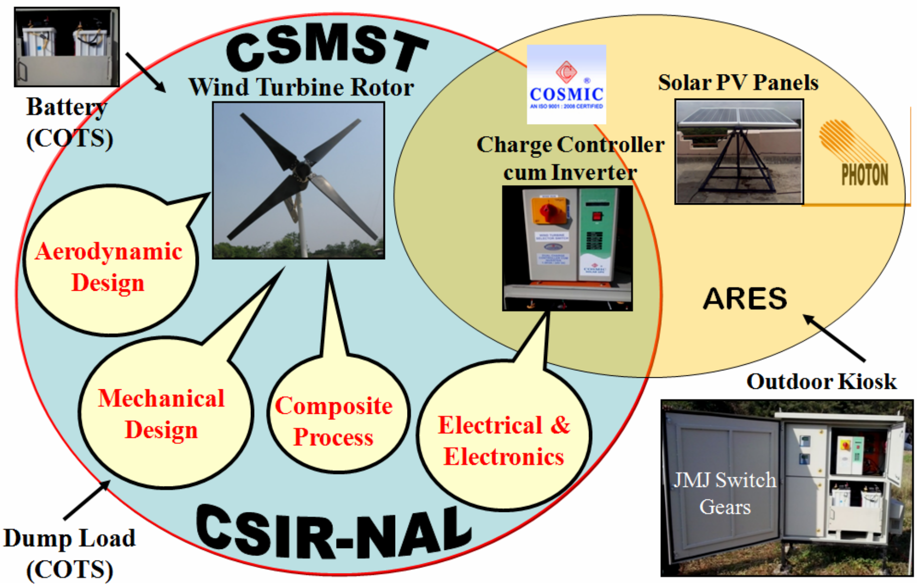


Figure 11 Networking with MSMEs for development of WiSH System

4. Conclusion

The key challenges that were addressed in Research, Design, Development and Demonstration (RD^3) of the WiSH system have been brought out. NAL envisages to continue research further in areas of aerodynamic augmentation devices to improve the performance, carry out research on Natural Fibre Composites & light weight structures to come out with eco-friendly ultra light composite blades, develop simple and cost effective Control system with MPPT modules and subsequently scale up the WiSH system to 2 – 5 kW capacity.

Apart from this, NAL, along with ARES, also envisages to take up a Limited Series Production of 50 Units of the WiSH System. Type certification of the wind turbine, a part of the WiSH system, by CWET will also be obtained. This apart, we intend to disseminate the information about the WiSH system at various Academia, Renewable Energy forums in India and amongst the prospective end users such as the renewable energy agencies of N-E states.

5. Acknowledgements

The authors wish to express their heartfelt gratitude to the Director, CSIR–NAL and staff of CSMST who have contributed to the RD^3 of the WiSH system. Our special appreciation to the organizers of the Indian Technology Congress 2014 for providing a forum to present this paper and disseminate CSIR-NAL's efforts on to develop the "*Swadeshi*" technology for strengthening India's Renewable Energy Program.

Reference

[1] http://mnre.gov.in/schemes/decentralized-systems

[2] http://www.gl-garradhassan.com/en/software/GHBladed.php