Applications and technological development of vertical axis wind turbines of Hi-VAWT Technology Corp.

In 2005 Hi-Energy Technology Co., Ltd. was founded. By the help of the support under the SBIR (Small Business Innovative Research) phase 1 and 2 in 2006 the company started to design small vertical axis wind turbines.

Application sites

With the preliminary technical basic principles the company was looking for his target group. The events in the following years including the incident in Fukushima 2011 caused a decrease of trust in central power generation. Many countries began to support decentral power generation in order to reduce the dependence on the power supply system. Traditionally small decentral diesel generators were operated but fuel transport and O&M costs are high, in particular at remote off-grid sites. Therefore governments started to consider renewable energy hoping that costs for O&M costs will drop.

In a target market of a decentral power generation the applications of grid and off-grid purposes of wind turbines made by Hi-VAWT are described as follows:

1. Off-grid decentral power generation

According to the United Nations it is expected that 600 Mio. people in rural and remote areas in developing countries will be provided with electricity by 2015. Since the construction of traditional central power plants in these areas and the installation of cables to the customers are too expensive and not feasible a decentral power generation system with off-grid sites is getting attention. Hi-VAWT products for applications in terms of a off-grid decentral power generation are:

a. Grid monitoring/telecommunication station

Telecommunication station, Korea

Telecommunication station, Tibet, China

China Mobile telecommunication station, Xinjiang, China *b. Wind and solar lamps*

Wind solar hybrid system for parking lot lighting, Ibaraki, Japan

Wind solar hybrid system for road lighting, Shanghai, China *c. Polar research station system power supply*

Power supply for research station, Antarctica

2. On-grid decentral power generation

If there is a central power generation structure, a local fault can cause a chain reaction and finally a large outage. So the security of supply cannot be ensured. In a decentral power generation system it can happen that the local demand exceeds the power fed into the grid. In this case neighbouring areas with decentral power plants can be used. So the grid is not as vulnerable to failures as a grid fed by central power plants. Moreover it improves the energy efficiency. Applications of Hi-VAWT products for an on-grid decentral generation system are:

a. Energy recovery system

Energy recovery system at AU Optronics, Taichung, Taiwan *b. Energy supply on rooftops in metropolitan areas*

Rooftop application at EMSD building, Hongkong

Rooftop application at a TESCO store, Korea *c. Wind farms*

Small scale power plant, Nemuro, Japan

Technological development

In order to supply this market, Hi-VAWT promoted the development of the required technologies. The required features of these technologies are described as follows:

1. Off-grid applications have to be sufficient reliable

Because of the small size of the wind turbines the transport to the sites is not a big problem. The turbines can supply power to electrical devices at remote locations where the grid power and reliability have to kept stable. A new series of Hi-VAWT wind turbines designed in particular for off-grid decentral applications include the following technologies:

a. Increase of generation capacity by improved Maximum Power Point Tracking (MPPT)

The kinetic energy of the wind is converted into kinetic energy of the rotation of the wind turbine blades. The rotational speed is ruled by the wind speed. At a fixed wind speed a wind turbine shows the following processes: The blades experience a drag and lift force caused by the wind and convert the kinetic energy of the wind into rotational energy. The higher the wind speed the higher the rotational speed. The acceleration of the rotation increases until the speed reaches a specified value. The wind turbine has a maximum torque.

The wind turbine extracts the maximum energy at maximum power. The procedure that finds this point is called Maximum Power Point Tracking (MPPT).

However the wind speed changes very fast in nature. There is no easy way that the MPPT can catch these fast changes. Therefore a checkout table is used.

Since the wind speed influences the power of the wind with the 3rd power the converted kinetic energy of the rotating blades of the wind turbine is also influenced by the 3rd power of the wind speed. So the maximum energy is proportional to the cube of the wind speed and it is crucial to find the proportionality constant. The unknown rotational speed at different wind speeds can be determined in a wind tunnel. Once enough values are determined a c_p-TSR-curve can be drawn.

There is a theoretical maximum c_p-value at 16/27=0,59259... . If wind turbine manufacturer claim their turbines can reach a c_p higher than this value, it is just a wrong statement. Moreover saying to have a c_p higher than 1 means that more energy would be extracted than there exists originally. That would not be conform to the law of the conservation of energy. However there are methods to optimize the turbine like aerodynamic properties to improve the efficiency of the wind turbine and to get close to the theoretical maximum of c_p. Performance tests are conducted to get the c_p-value. The test procedure is determined by the norm IEC61400-12-1. Testing platforms and all instruments used for the test have to be certified by the TAF (Taiwan Accreditation Foundation). According to the BSMI (Bureau of Standard, Metrology and Inspection) there are 2 locations in Taiwan having this certification: the testing farm of the metal processing center in Chigu and the power testing farm in Penghu.

b. High wind generation capacity by improving the protection and control of the rotational speed

At wind turbines the captured kinetic energy is converted in kinetic energy of rotation. If the wind speed is too high, the rotational speed becomes also too high and the centrifugal force exceeds the upper limit of the mechanical stability of the turbine and can cause damage. So during the designing of a wind turbine a protection against rotational speed excess should be kept in mind. Therefore plenty of tables mentioned in the norm IEC61400-2 for small scale wind turbine design have to be considered. In case of a simple stress load case E, an evaluation of maximum speed stress for wind turbines, is used. Load case H is the evaluation of the maximum stress limit of a wind turbine at thrust.

Since until now the IEC-specification is not valid for the simple load case of vertical axis wind turbines Hi-VAWT started a cooperation in 2010 with the Institute of Nuclear Energy Research to design a vertical axis wind turbine for the simple load case. The result is mentioned in "CNS15176-2-1" in the norm GB/T 29494 "Small vertical axis wind turbines" in 2014. Performance and safety requirements are described in annex B. In June of the same year similar load cases have been described in the Japanese norm "JSWTA-0001" annex C. The International Energy Agency (IEA) founded a task force (IEA Wind Task-27) for the wind systems research and development by the cooperation agreement article 27. Taiwan is focused on the results of this task force, for which the IEC61400-2 is the basis.

By these simple load model calculations it is obvious that the load limit of maximum rotational speed of load case E is the centrifugal force. Under load conditions like in load case H the maximum stress limit is higher for thrust at higher wind speeds. Therefore the rotational speed protection occurs normally at high wind speeds. At horizontal axis wind turbines normally the angle of attack of the blades can be changed to avoid high rotational speeds at high wind speeds. At vertical axis wind turbines it is not easy to reduce the intensity at the blades by a rotational speed protection. The wind turbine can run in a safe way due to the speed controller. In 2013 Hi-VAWT finished his product development plan succesfully according to the regulations of the ministry of economics. This plan includes the features mentioned above. The controller is an international patent.

If the wind turbine has no protection for rotational speed exceedance the wind turbine has to be switched off before the wind speed limit is reached and so generating power at high wind speeds are missed. If a reliable and efficient protection for rotational speed exceedance is installed not only power can be generated at high wind speeds but also the total power output can be increased. The results must be proven by a field test to ensure that the achieved power output is reliable. The test procedure is determined in the norm IEC61400-12-1. Parallel to the increase of the power the safety of the wind turbines have to be ensured. This is conducted by a long-term field test determined in the norm IEC61400-2 and CNS15176-2 annex G.

2. Applications have to consider needs of residential areas

Small scale wind turbines often are used near residential areas. Therefore safety and comfort have to be taken seriously. The most important technological developments of new products of Hi-VAWT considering this are:

a. Improvement of the mechanical stability of the turbine

Hi-VAWT designed a wind turbine in spring 2005. This turbine was analysed by Sandia National Laboratories in USA to get plenty of data by wind tunnel tests and other methods. The hybrid blade structure allows an easy start due to drag force type blades and high efficiency due to lift force type blades.

According to simple load model in CNS15176-2-1 annex B load case A can be evaluated. At normal operation wind turbine blades get in 20 years of operation only 6-8% fatigue damage. Rotor blades can be improved by the mechanical stability. This can be proven by durability tests mentioned in IEC61400-2 and CNS15176-2 annex G. Functionality and safety are ruled by IEC61400-2 and CNS15176-2 annex G. Statical endurance testing for the blades are described in IEC61400-23 and CNS15176-2-1.

b. Reduction of mechanical and aerodynamical noises

The main noises are caused by the high frequency noise of the blade tip vortexes and low frequency noise of the vibrations at the gear box and generator coil. The high frequency noise of the blade tip is proportional to the 6th power of the relative wind speed. The tip speed ratio (TSR) is defined as the ratio between the flow speed tangential to the blade tip and the wind speed. Wind turbines of Hi-VAWT extract the maximum energy at a TSR being low compared to TSR of horizontal axis wind turbines. Therefore their high frequency noise is much lower than that of horizontal axis wind turbines.

Wind turbines of Hi-VAWT uses direct driven synchronous generators. Thus less energy is going lost and low frequency noise is avoided due to the missing gear box. However there is still low frequency noise caused by mechanical vibrations at the generator coil. This is increased by the resonance. By increasing the mechanical stability of the casing material vibrations can be filtered and reduced and hence the resonance as well. So mechanical vibration noise of the generator coil can be avoided due to the lower frequency. In 2007 Hi-VAWT got the multinational patent of the noise avoidance. Avoiding noise is crucial for installing wind turbines in residential areas.

The efforts to reduce noise can be proven by different wind noise measurements at TAF certified wind turbine testing sites. The test procedure is in compliance with the norms IEC61400-11 and CNS15176-2. Noise emissions can be expressed in a way of AWEA

(American Wind Energy Agency) and BWEA (British Wind Energy Agency, renamed to RenewableUK). Even though the testing methods follow IEC61400-11, the AWEA standard dictates that at a required annual mean wind speed of 5 m/s the noise emissions must not exceed the limit during a year in 95 % of the time.

The requirements of the BWEA dictates the emission limit must not allowed to be exceeded in 90 % of the entire time during one year at a mean wind speed of 5 m/s.

Meanwhile IEC61400-11 sub-divides noise measurements as well. The Taiwan EPA (Environmental Protection Administration) noise emission norm can also be used. This standard includes 4 types of wind energy noises depending on land use and land area. These types are sub-divides into 3 daytimes.

c. Suspension design for avoidance of vibration transfer

Due to changes of thrust and vibrations a multi axis acceleration meter can be mounted on the tower. It is able to measure the vibration acceleration. Vibrations causes fatigue damage.

Absorbing air pressure efficiently can reduce resonance accumulation. Tower vibrations are estimated to be reduced up to 80 %. Damping testing results are in compliance with the norm for vibration measurement VDI3834 (Association of German Engineers). According to this norm the vibration acceleration is safe if it is less than 0,3 m/s^2, cautious between 0,3 and 0,5 m/s^2, and heavy at more than 0,5 m/s^2. At this point it is recommend to stop the testing. The DS3000 of Hi-VAWT was tested according to VDI3834. The vibration acceleration was 0,261 m/s^2 and so less than 0,3 m/s^2. Thus the turbine is certified for long-term operation.

d. Influence of downwind vortex

The wind speed at the rotor plane is the arithmetic mean of the upwind and downwind wind speed. To extract the maximum amount of energy the downwind wind speed hat to be 1/3 of the upwind wind speed.

Horizontal axis wind turbines show a typical vortex at the downstream area. For this reason it is difficult at low wind speed to mix the wind at the downstream area. Normally at a distance of 8 times the rotor diameter after the wind turbine the downstream wind speed reaches the same wind speed like upstream. Vertical axis wind turbines do not have such an intensive vortex. Therefore the wind needs downstream only 6 times the rotor diameter to reach the original wind speed again. The new blades reduce the vortex in the downstream area. The DS3000 turbine was designed by a CFD (Computational Fluid Dynamics) simulation of the Institute of Nuclear Energy Research. In this simulation the velocity and the vorticity of the wind were analyzed. By this research vortices occur only in a downstream area that has a length of 3 times of the rotor diameter. Therefore several wind turbines by Hi-VAWT can be erected close to each other.

e. High-rise applications enhance the turbulences and performance

In order to regulate the situation of all types of wind turbines on rooftops in urban areas the IEA Task 27 published a paper in 2014.
The NTU (National Taiwan University) measured the amount of the Tamsui river at the Taipei College of Maritime Technology.
The roof was erected for the new DS3000 turbines of Hi-VAWT.

At the moment an international team of IEA Task 27 analyses the performance of power generation on rooftops of high-rise buildings with turbulences. Among the team members are USA, Australia, Japan, Ireland and Spain. A CFD-Analysis is used. Concerning the USA the Wind Energy Research Center of the NREL (National Renewable Energy Laboratory) conducts turbulence measurements on the roof of the NASA Johnson Space Center.

In the past 9 years Hi-VAWT have won several international awards like the National Innovation Award of Korea 2009. The turbines are considered by SK Telecom as being the only accredited small wind turbines. Moreover Hi-VAWT won the Korea Samsung Construction Award 2010 for the zero carbon construction plans. The products of Hi-VAWT were used as the only small wind turbines at the Shanghai World Expo 2010. In 2011 the DS3000 was accepted to the list of material procurement rules of Chunghwa Telecom Taiwan.

Since the foundation in addition to research and development Hi-VAWT has been investing in products also in areas not belonging to vertical axis wind turbines. To ensure performance and safety the products follow international standards. Therefore Hi-VAWT has been investing continuously in international proof and certification procedures. In 2008 Hi-VAWT ordered the British certification center TÜ Vnel for certifying the new DS3000, which was finished in October 2010. Thereby it is the first vertical axis wind turbine worldwide which has fulfilled the requirement of IEC61400-2. The IEC61400-2 set in May 2011 for the first time rules for testing of small-scale wind turbines. All turbines of Hi-VAWT (300 W, 1,5 kW and 3 kW) were tested at the national tests wind field in Jeju (Korea) in accordance with ICE61400-2. In June all types (300 W, 1,5 kW, 3 kW) have finished their certification process in Korea.

Moreover 1,5 kW and 3 kW wind turbines of Hi-VAWT received the ETL safety certificate of Intertek, a certification company located in UK. Hi-VAWT's DS3000 turbines were certified by Nippon Kaiji Kyokai (ClassNK) in June 2013. By this the turbine was the first one getting an certification in Japan. For this reason the turbines are allowed to get the FIT of the Japanese government. Furthermore the DS3000 passed in December of the same year the grid parallel inverter test in Japan.

In March 2014 Hi-VAWT was authenticated by the BSMI and committed the recognized technical test report for the DS3000 by the metal processing center. The INER certificated the formal examination of the technology reports of the DS3000. At the moment the DS3000 is the only small wind turbine worldwide having received the voluntary certification in Taiwan.