WHITE PAPER

The future is energy efficient, energy yields and revenue

Introduction

Wind power production has now become a truly viable business, without the need for government support. The next challenge is to further improve the levelized cost of wind energy to further increase its competitiveness and thereby assist in reaching carbon neutrality targets.

Here we present an extension to the ACS880 frequency converter family, with which an increase of 1-3% in wind turbine electricity generation can be obtained. This creates revenues that immediately affect the bottom line.

The 1-3% gain is accomplished by using a new approach in power conversion technology that raises the power output while keeping the voltage rating in the low-voltage (LV) range. At the same time, the new method requires less space in the nacelle, providing further design and operating benefits for better overall cost competitiveness.

Our new approach relies on ABB's experience in providing 3-level medium-voltage (MV) converters for 10 MW+ class offshore turbines and LV solar converter applications. But now we apply them to the onshore market, where turbine ratings of 5 MW+ are the new norm.

Improvements through the years
Early wind turbines had no frequency converters. The first turbines were simply equipped with direct-on-line, connected generators that could handle only a very narrow range of rotational speeds for different wind speeds. Thus, some wind energy capacity was lost since it could not all be captured and converted as it passed by the turbine.

The second phase of development in modern wind turbines was to introduce two-speed generators that allowed a stepwise change of rotational speed. This was then followed by the current technologies with a rotor-connected, double-fed converter system and a full conversion system. All of these have progressively improved the capture of wind energy.

Based on these major improvements through the years, it is no surprise that wind is considered to be the most cost-efficient method of power generation, since onshore projects can today be accomplished without extensive financial incentive mechanisms. The efficiency comparison is purely based on the wind megawatt hour (MWh) cost versus the electricity MWh price on the open market.

By increasing the system voltage for the components located in the nacelle, it is possible to deliver higher power output without increasing the current.

Elements of energy yield improvements
By increasing the blade diameter – that is, the actual sweep area that the wind is passing through – the net collected energy is increased, making areas with even lower average wind speeds economically viable. Also, by raising the tower height, higher average wind speeds drive the turbine blades.

As turbine manufacturers have raised the rated output from the previously dominant 2 MW to the present 4-6 MW range and higher, the average electricity generation has clearly increased enormously. All of these elements can be seen in the current commercial turbine platforms.

It is important to note that each of these stepwise improvements have required major engineering and scaling efforts, and the biggest gains have now been implemented. The focus now can, and must, be put on getting further incremental yield improvements in annual energy production by upgrading the efficiency of the electrical power train.

This can be accomplished with a few straightforward modifications to the generator-converter-transformer setup which we will discuss here.

How to improve wind power financial returns
To make the overall financial equation of this promising renewable source even more attractive, there are many possible avenues that can be taken. And for turbine OEMs, investors, and operators, making the right choice is critical to achieving superior long-term success and payback with any wind power investment.

The promising strategy that we are pursuing at ABB offers the potential to reach several key targets simultaneously in a practical and economical manner and letting operators increase the energy yield using a fairly simple method. We propose to do this by increasing the system voltage for the components located in the nacelle, thus delivering higher power output without increasing the current.

This means that, for the greatest cost effectiveness with respect to the initial investment and ongoing O&M costs, the best strategy is to boost the voltage to the upper limit of the low-voltage level. This is the key to getting the optimum cost per MWh.

990 V converter gives numerous benefits
We expect high demand for a concept that can give higher returns while remaining in the low-voltage classification. To do this in practice and meet this demand, ABB is introducing a new converter.

We consider this product to be suitable for wide adoption in the wind industry. It can result in receiving more annual energy from the same turbine, and thus reduce the levelized cost of that energy.

Currently, most wind turbine power conversion systems are based on 690 V technology. With the trend toward increasing ratings of wind turbine power, and a need to improve annual energy production, 690 V is clearly no longer the optimum level.

Our approach suggests raising this 690 V technology to 990 V. By increasing the voltage like this, the electrical current needed to transfer the power is less. A lower current in power transmission parts like the generator and main transformer translates into reduced losses (meaning increased power capacity) in all areas of the turbine operating points.

Advantageous low-voltage rating

Because the voltage range we are proposing remains under the 1,000-volt level, OEMs and turbine operators can still operate the power converter as low voltage equipment, as defined by the European LV directive. This gives the substantial benefit of not requiring any additional training of operational personnel.

In addition, with today's trend in the wind industry to place all of the power transmission components in the nacelle, the 990 V equipment requires less space, therefore gaining the benefits of compactness and a smaller overall nacelle size.

The hardware needed to make this voltage range adaption is available using commercial, high-production volume power electronics – but with advanced and patented control methods. Specifically, a 3-level converter based on proven power electronics technology is used and combined with ABB's patented control methods to make it suitable for both direct-drive gearless turbines and high-speed geared turbines.

Using 3 DC voltage levels gives many benefits
When the AC voltage is created with three DC voltage levels (the so-called 3-level technology) instead of the traditional 2-level technology, we can raise the voltage from 690 V to 990 V and still utilize the available, large volume power electronics already in use for 690 V on an industrial scale.

Using 3-level topology enables the use of a lower individual switching frequency for the same AC voltage waveform, meaning less stress is posed on the individual switch.

With 3 levels instead of 2 there are more switches (18 instead of 6), so the stress posed on each is clearly lower. A simple analogy might be to think about a 10-ton load placed on two equal-sized wagons: one with 6 wheels and one with 18. Obviously, the weight/stress on each wheel would be less for the cart with 18 wheels.

At the same time, 3-level topology gives increased amplitude to the voltage waveform, reducing the generator current at the same power output. This lower current means lower power losses in resistive components throughout the system – namely in the generator, transformer and connecting cables and busbars. The losses are reduced to the squared power of the reduced current when travelling through resistive parts of electrical circuits as expressed by this equation: (P=I^2*Rloss).

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2-level converter configuration

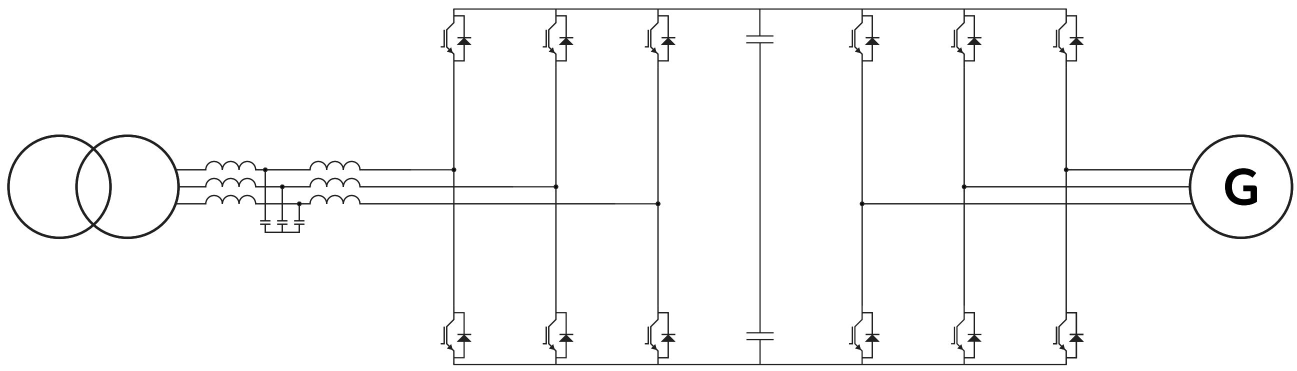

Figure 1.
In a traditional 2-level system, the AC voltage waveform is created by two switches which turn the voltage to either 100% or 0%.

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3-level converter configuration

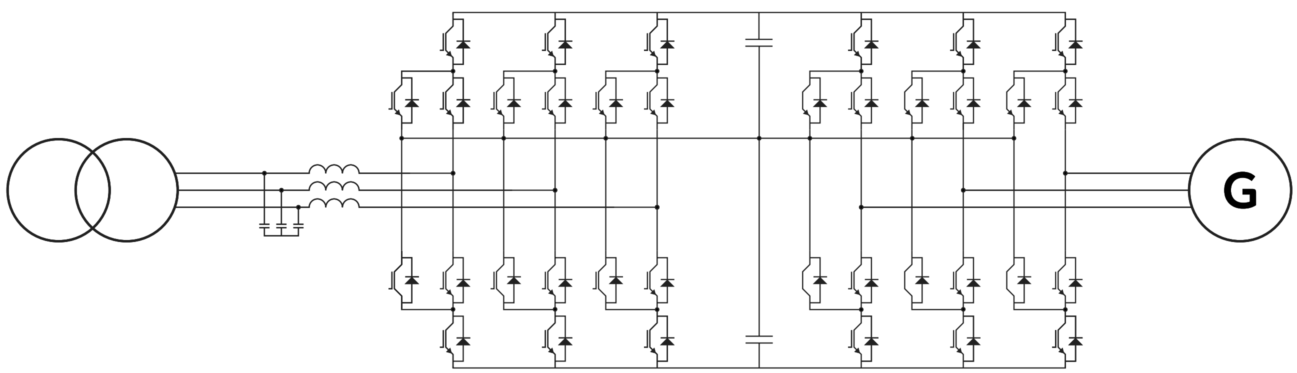

Figure 2.
The 3-level system includes an additional step at 50%, enabling smoother generation of the AC voltage waveform – resulting in lower current harmonics. With less harmonic content in the current, less losses are generated in the system, meaning one more additional step for higher revenue.

Further efficiency gains in the transformer and cabling
Before we introduced this new concept, if wind turbine builders wanted to increase power with 690 V it would mean higher phase currents. This in turn leads to more winding in the transformer and increased temperatures in cable terminal boxes, meaning higher costs.

Instead, by increasing the voltage to 990 V designers can now get more efficient transformer and cabling solutions. In addition, with the high switching frequency of IGBTs, the 3-level converter topology improves the voltage waveform significantly and consequently reduces harmonic losses in the transformer windings.

With 3-level modulation the rated RMS voltage is higher as well. This maintains peak voltages that are approximately the same as with a conventional (690 V) 2-level converter, thus allowing the generator designer to maximize the benefits of the higher voltage.

Electrical Drivetrain Comparison 690V (2L), 990V (3L) and 3300V (3L) (IEC 61400-1, Weibull k factor)

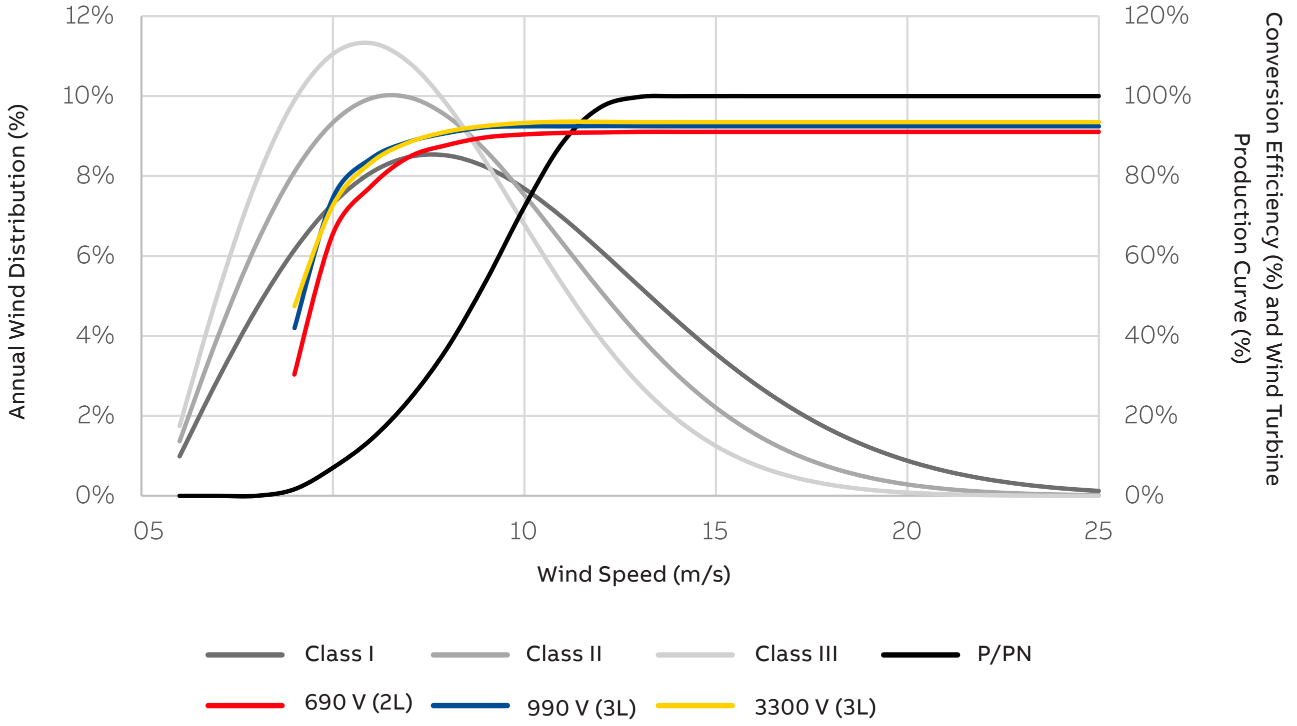

Figure 3.
An example of efficiency changes with 2-level 690 V, 3-level at 990 V and at 3300 V. Efficiency improvements take place at partial loads which gives contributions to annual energy yield at every wind speed.

Extra 1-3% energy revenue goes straight to the bottom line
With wind energy now viable without government subsidies, the focus has become maximized return on investment. For those who are investing in new turbines, the series of steps outlined in our new low-voltage concept allow you to run at a higher voltage level, thereby easily improving annual energy production by 1-3 % – improving the bottom line.

As an additional benefit, existing turbine types can enjoy the same increased returns made possible by this design upgrade – simply due to the fact that the respective turbine curve is improved and optimized.

It is important to realize that these benefits can also be applied to the growing turbine repowering market, where complete nacelles with generators and blades are replaced by new ones. When doing such a repowering, it would naturally make sense to optimize the electrical power train to the 990 V level, since it is going to be replaced anyway.

Whether this 3-level converter technology is applied to a completely new turbine model or an upgraded one, the overall result is the same: Improved payback on the investment.

Shifting the curve up 1-3%
The return on a wind farm investment relies on the annual energy production of the site. Therefore, the number of turbines, the turbine power curve and turbine locations at the site are decisive for annual revenue flow. We can compare the electrical power curves of a 690 V and 990 V turbines and see the improvement. That is, that without any adjustment in aerodynamics or mechanics, the same turbine will have a higher annual energy production (AEP).

The improvements take place at system level, meaning in the electrical power train from generator to converter and transformer. Therefore, we can only give an improvement range of 1-3% instead of a fixed percentage.

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Turbine AEP improvement with 990 V to 690 V

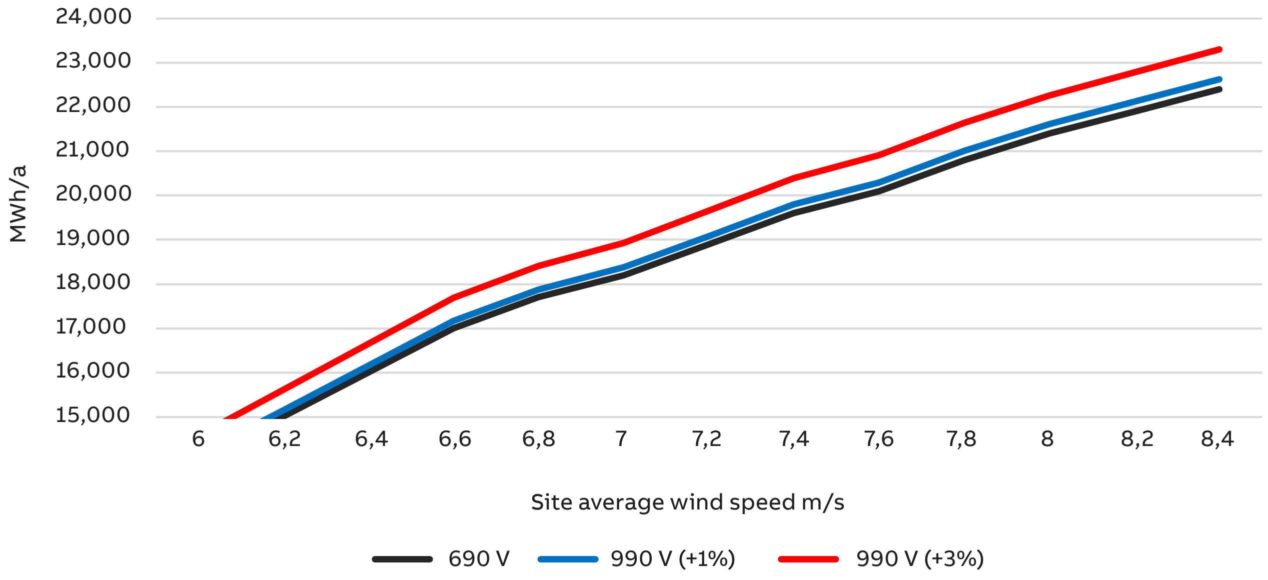

Figure 4.
Impact of electrical drive train improvement on annual energy yield at different average wind speeds.

Annual wind farm (of 150 MW, at 40 €/MWh) revenue increase (30 turbines)

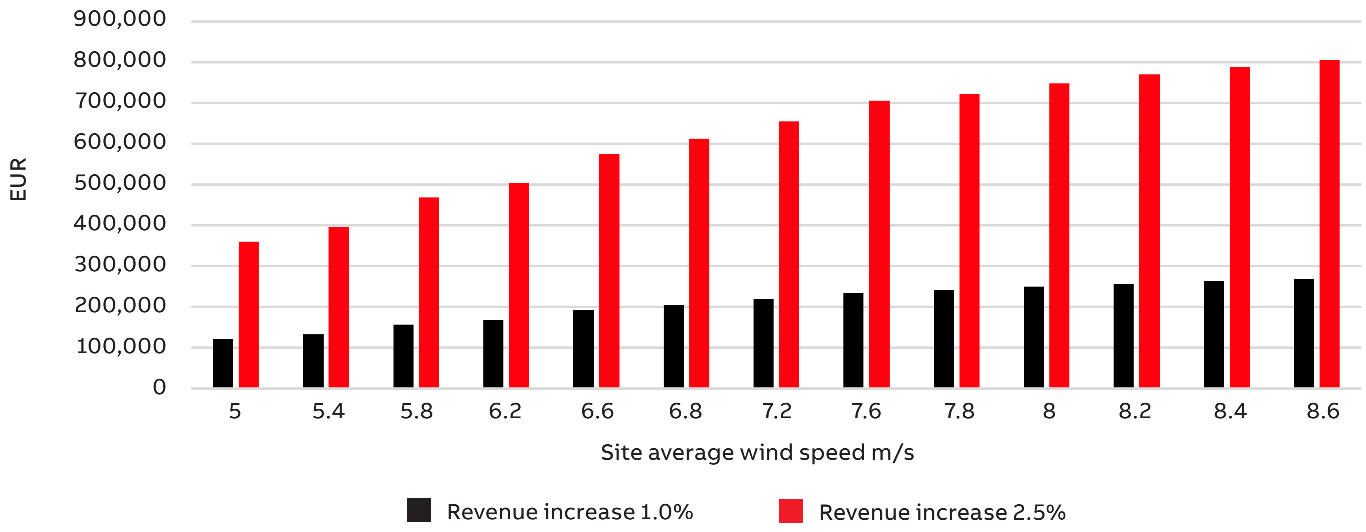

Figure 3.
Increased revenue estimates for 3-level converter with 1.0 % and 2.5 % added revenue.

At repowering sites where existing towers are used and nacelles replaced with new ones, it is not any extra effort to change the voltage of the drive train. In fact, an extra revenue flow with no additional cost is created.

Conclusion

990 V makes a big difference
As an example, let's take an investment of a 150 MW wind farm with around 30 turbines at 5 MW rated capacity. If the proposed turbines have an internal power conversion of 990 V instead of 690 V, the owner will enjoy an annual revenue improvement of 1-3% for every year for the life of that wind farm. This makes a big difference in both cash flow and speed of payback.

Considering two similar investments to an electrical power train, a difference of 1-3% added revenue every year demonstrates the benefits of the 990-voltage level converter. It is not only new sites than can benefit from this approach. At repowering sites where existing towers are used and nacelles replaced with new ones, it is not any extra effort to change the voltage of the drive train. In fact, an extra revenue flow with no additional cost is created.

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