Advantages Realized Through the Use of Vindicator™

The following list contains eight areas associated with wind energy generation where, through the use of Vindicator™, definable and quantifiable advantages will be realized. These advantages will result in increased profit to the wind farm operator through increased energy output, reliable energy scheduling, and lower maintenance costs. Vindicator™ will increase the bottom line by 10% and reduce the occurrence of catastrophic turbine failure due to wind shear and unexpected gusts!

Vindicator™ works by integrating with a wind turbine's control system, or electronic brain – Vindicator™ will actually sense the wind that is approaching the wind turbine at a range of 300 meters, and report this information to the controller in sufficient time for the controller to affect changes to the turbine. Utilizing control algorithms, the controller will decide how to best exploit the wind that is approaching the turbine and command internal systems to either change blade pitch and/or re-orient the entire nacelle in an effort to maintain efficiency, reduce the effects of wind shear and gusts, or maintain a constant blade speed. Without Vindicator™, wind turbines will always be out of phase with changes in the prevailing wind.

1. **Safe and Efficient Wind Utilization:**
    a. **Nacelle Yaw Control**:

The average wind turbine is out of alignment with the wind throughout most of its operations. The wind is always changing direction; even when wind on average is steady from one heading, transient changes in heading of as much as 15 degrees are common. For every degree out of alignment, energy output drops by 1%; a turbine that is only 15 degrees out of alignment loses 15% of its efficiency. Vindicator™ sees the wind as it approaches the turbine and allows the controller lead time to orient the blade disk into the wind and keep it pointed into the wind. Decreasing the average out of alignment condition from 15 degrees to 5 degrees will result in a 10% increase in turbine power output.

    b. **Blade Pitch Control:**

In addition to keeping the blade disk oriented into the wind, blade pitch position is equally important to turbine efficiency. Turbine blades are the devices that turn wind energy into mechanical energy. The more efficient the blades are, the more energy is transferred to the turbine generator. Turbine blade efficiency is a function of pitch or offset angle to the wind. Just as wind *direction* varies, wind *speed* varies greatly as well, as a result of the gusts, lulls, and turbulence which are always present. Blade pitch, relative to wind speed, determines the amount of energy gleaned from the passing wind; with the accurate and timely information provided by Vindicator™, the turbine controller will be better able to harvest energy and control loads from the wind.

An additional problem encountered by wind turbines is noise generated by the spinning blades when encountering turbulent air – under certain conditions, some turbines emanate a low frequency noise which some people find offensive. Permitting and site selection is made more difficult when this occurs. Vindicator™ will sense approaching turbulence and enable intelligent blade configuration, thereby eliminating the annoying acoustics.

Logically, effective blade pitch control will expand the wind turbine's operating envelope and enhance the following features**:**

1. **RPM Control:**

As with any mechanical device, a wind turbine has mechanical thresholds and limits. When a limit is exceeded, component failure will result; when a threshold is not met, the turbine will not operate. In either case, the turbine is no longer producing energy. Vindicator™ will enable a wind turbine to efficiently adjust blade pitch based on the wind that is *approaching* the turbine in order to achieve and maintain the optimal blade disk revolution rate, or RPM. RPM control is critical to wind turbine structural survival – if turbine blades spin too fast, the blades will depart the turbine resulting in catastrophic failure; if RPM drops below an optimal rate, the turbine generator is less efficient and the turbine will not develop its rated power.

Additionally, many turbines utilize an electrical generator which is linked directly to the turbine rotor disk and is dependent on turbine RPM to operate efficiently and to maintain the phase of the electrical output. Elaborate means are employed to hold phase because without knowing the approaching wind conditions, precise RPM control is impossible. Vindicator™ is the key to active and effective RPM control.

2. **Low-speed Wind Efficiency:**

Due to growth in the wind energy industry, most of the *best* wind sites in North America have been developed – what that leaves for future development are the less desirable, lower average annual wind speed sites. This will drive development of turbines that will be operated in lower speed, less consistent winds. Vindicator™ is critical to ensuring the success of these operations because Vindicator™ will see the wind and report small variations in sufficient time to enable the turbine to configure for optimum exploitation. Even a slight increase in the annual harvested wind results in a large increase in annual power generation, because the energy that can be tapped from the wind is proportional to the cube of the wind speed. Therefore, even in low wind conditions, with Vindicator™ significant power output and profitability is realized.

RESULT: Energy output annual gain of 10%

2. **Increased Component Lifetime/Reduced Maintenance Costs:**
   a. **Asymmetrical Load Alleviation:**

The wind energy industry states that 10% of the annual cost to generate a kilowatt hour (KwH) of energy is directly attributable to maintenance and repair costs. The benefits realized with Vindicator™ go beyond increased efficiencies in energy production – it effectively reduces stress on mechanical components. Seeing the wind and orienting into the wind reduces side load, or off-axis stress, felt by the turbine. Bearings, nacelle mounts, and supporting structures are designed to handle stress from certain directions; the cost of over-designing mechanical components because of the uncertainty of wind loads would make wind energy cost prohibitive. Government estimates indicate that Vindicator™ controls will reduce overall component wear by 10% annually, thereby increasing dynamic component lifetime.

b. Wind Shear:

Wind turbines are very large, some over 300 feet tall, and often experience very different wind speeds and direction at the top and bottom of the rotor disk. These unbalanced forces generate an enormous amount of stress on the blade hub. This added stress translates into increased hub bearing wear, generator drive-train wear, and support structure fatigue: it is very common for a turbine to require major repairs long before making it out of warranty. Vindicator™ sees the wind that is coming and can report variations in speed and direction to the turbine controller. This allows sufficient time for an individual blade to adjust pitch, allowing the wind gust to pass, thus reducing an increase in stress on the blade and felt at the hub. In high wind conditions, blades, which have not been adjusted, have been known to flex so much that they have actually impacted the support tower - resulting in catastrophic turbine failure.

RESULT: Maintenance Costs Reduced by 10%

3. **The Bottom Line**:

a. **10% increase in energy output translates to increased revenue.**

The following example shows the additional income generate through the use of Vindicator™ on a typical wind farm:

- 50 Turbines rated at 2MW capacity = 876 million KwHrs annually.
- Average annual power generated = 306.6 million KwHrs.
- Energy output increased 10% = 30.7 million KwHrs annually.
- Revenue increased by $1.84 million (based on $0.06/KwH)

b. **10% reduction in maintenance costs.**

Using the example above, utilizing Vindicator™**:**

- Annual power generated = 337.3 million KwHrs.
- Annual revenue ($0.06/KwH) = $20.24 million
- Annual Maintenance costs = $2.02 million
- 10% savings on maintenance costs = $0.202 million

c. Energy production reliability and predictability.

Taken as a whole, Vindicator™ adds a level of reliability to the wind energy production industry. Increased average annual production will result in higher prices being paid for wind energy on the spot market. Energy price is a function of capacity factor; by increasing the capacity factor of a wind field through an increase in average annual output, producers can demand a higher rate for the electricity they produce. A wind field operating at 35% overall efficiency before introducing Vindicator™ will be able to increase overall efficiency by 10% - thereby increasing its capacity factor by 10%. An increase in capacity factor translates to a reduction in risk for the energy consumer – reliable energy yields greater returns to the producer.

Vindicator will increase the average wind farm's annual revenue by $2.1 million, reduce the occurrence of catastrophic turbine failure and acoustic interference, and add a level of stability to the wind energy spot market.