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Feature article

The "Selfish Invention"

Part 1: Chris Varrone gives us a preview his latest research on the impact of variable speed concepts for wind power, starting with a look back at Kenetech.

IN 1976, Richard Dawkins, an evolutionary biologist at Oxford University, introduced the concept of the "selfish gene." According to this theory, human beings and other organisms can be seen as merely the means by which genes reproduce themselves. While at first this may seem like a parlor game, like looking into a telescope backwards, this theory has been quite successful on shedding light on thorny problems like the origin of human altruism and why bees maintain a monarchy. In the history of science, it also sometimes seems as if ideas have lives of their own, as if they are coming willy-nilly and just use us humans as a means by which they come to light. Historical examples abound of multiple independent discovery. It is as if calculus were the sentient being and Newton and Leibniz just the means by which calculus made its entrance onto the world stage. The list is indeed long, and includes the discovery of oxygen in the 18th century; and the theory of the evolution of species in the 19th century.

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In the history of the wind industry, arguably the greatest invention has been the introduction of the Variable Speed Wind Turbine, which was developed independently on both sides of the Atlantic in the late 1980s and early 1990s. Despite a wild series of bankruptcies and dramatic incidents (including alleged industrial espionage), the invention transformed the industry. And when one hears the whole story, including the multiple independent discovery and the fact that the inventors involved did not reap the fruits of their labor, it really seems as if "variable speed" were the actor and the men and companies involved (eg., **Enercon, Kenetech**) were instruments of this grand idea.

This article describes the introduction of variable-speed, pitch-controlled (VSPC) wind turbines that occurred primarily in the period 1995 to 2004. First, we recount the history of the early VSPC machines to understand the players, their motivations and ultimate fates, and identify the innovations and intellectual property that enabled their introduction. Secondly, we will see how patent-holders and first-movers failed to gain lasting advantage, and try to understand why this occurred.

Executive summary

Between 1995 and 2004, there was a revolution in wind turbine design in which variable-speed, pitch-controlled (VSPC) machines outcompeted the early fixed-speed, stall-controlled (FSSC) machines in the marketplace, rising from 14% to 73% market share. The variable speed concept was invented simultaneously on both sides of the Atlantic, giving the impression that the "selfish invention" was just an idea whose time had come.

The new machines succeeded (despite early setbacks), providing up to 10% greater energy capture and more grid-friendly operation. Moreover, the reduced loads at/near rated power reduced the structural materials required (eg. tower), enabling the enormous scale-up that occurred in the industry in this period, from about 100kW to 3MW, a factor of 30.

While the original VSPC machines did not live up to the hype of "5 cents per kWh," their successors did; this figure for cost-of-energy was reached by 2002, enabling wind turbines to compete head-to-head with fossil fuels, or nearly so. The global market for wind turbine generators (WTGs) exploded, growing 100% per year for over a decade.

The cost required to achieve variable-speed was initially quite daunting, as power electronics (IGBTs) in the early 1990s were expensive; however, as converter costs fell precipitously, VSPC machines could be priced at near-parity to FSSC machines, which themselves had to adapt via two-speed and active-stall techniques just to survive. By 2010, FSSC machines had essentially disappeared from the global market, and manufacturers like Nordtank, Micon, and Bonus were a distant memory.

Value creation during the period 1995-2004 was extraordinary: the global market for wind turbines grew from about 1000MW installed annually to over 11,000MW. Analysis shows that more than $3 billion in manufacturer margin was created over the decade – this equated to tens of thousands of high-quality jobs, dozens of factories and several personal fortunes. While many factors contributed to the growth of the industry, there is no doubt that the introduction of VSPC was a key enabler of turbine scaling, and that the industry would never have grown to such size if it had been limited to the 100kW models that were common in 1990.

The original patent-holders such as Kenetech Windpower did not reap the rewards of their innovation. Instead, three bankruptcies later, General Electric picked up the pieces of Enron Wind and their 1.5MW machine has surpassed 20,000 standing turbines, by far the biggest (and most profitable) seller of all time. The "selfish invention" found a way to market, even though its original host was long since deceased.

Historical transition

The scene opens in the late 1980s. With the exception of the machines from **US Windpower** (later renamed Kenetech), the wind turbines of the 1980s were fixed-speed and stall-controlled, "FSSC" machines. The machines had to produce AC power at grid frequency (eg., 60 Hz), and therefore ran at a nearly constant speed, for example 1800 RPM with a fixed gear ratio of 35:1. In this example, the rotor spins at 50 revolutions per minute and the generator shaft spins at 1800 revolutions per minute to deliver 60 Hz power. [*Variable-speed and pitch-controlled will herein be referred to as Variable Speed, Pitch Control or "VSPC" machines. There were also some intermediate concepts, e.g., "two-speed" and "active stall" machines from NEG Micon; also a few "variable speed stall control" devices (e.g., Northern Power 100kW). But mostly we can focus on the two pure types: FSSC and VSPC.*]

Between 1990 and 2005, three key developments emerged that contributed to the introduction of VSPC technology:

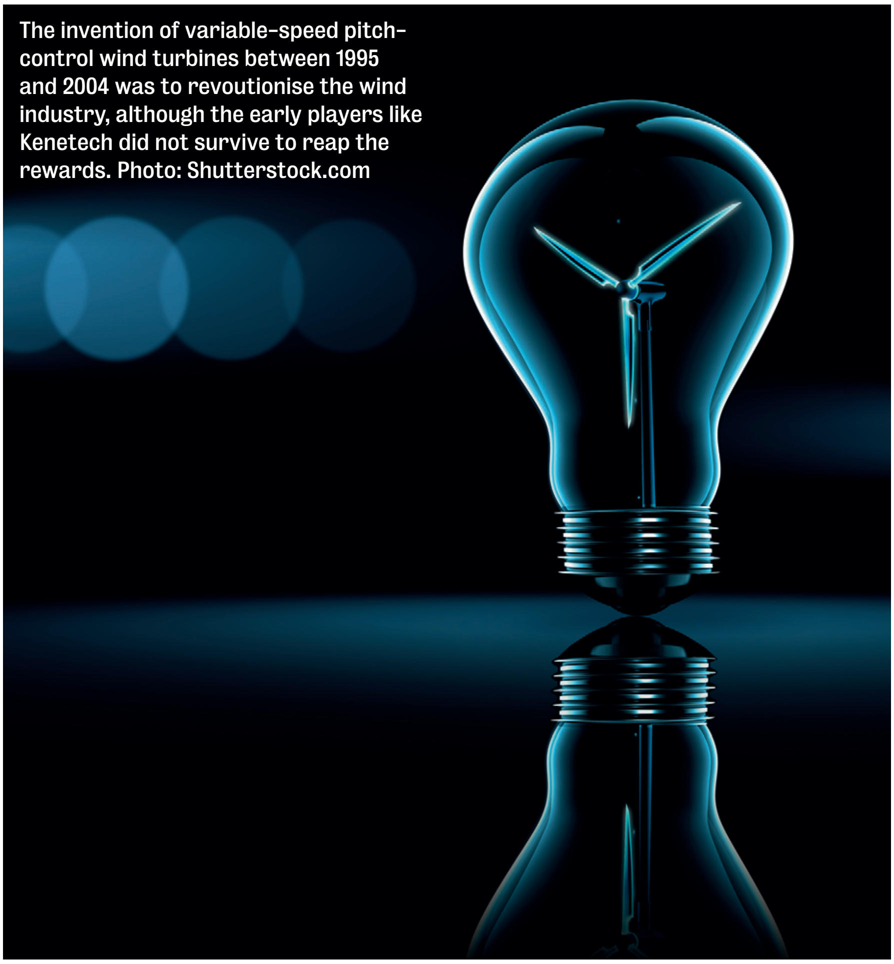
1. Kenetech Windpower pioneered VSPC, but went bankrupt in 1996.
2. Enercon developed similar technology at about the same time, but lost the IP battle in North America, and failed to rein in competitors in Europe, leading to an "also-ran" position by 2005.
3. **General Electric** acquired (from **Enron Wind**) the intellectual property originated by Kenetech, and used it to dominate the North American market with the GE 1.5MW turbine, the most popular WTG in history.

This section tells the story of the technology transition, and is divided into three parts, each devoted to one of the above themes.

North America: The Rise and Fall of Kenetech Windpower

As late as 1991, essentially all major turbine manufacturers were offering Fixed Speed machines, and most of these were stall-controlled:

In the article in which the table above appeared, there was a footnote about a 400kW prototype that was to begin production in 1993, ie., the USW



The invention of variable-speed pitch-control wind turbines between 1995 and 2004 was to revoutionise the wind industry, although the early players like Kenetech did not survive to reap the rewards. Photo: Shutterstock.com

33M-VS. This was to be a historic machine.

As described in *"The Five-Cent Turbine"* in *Powering the Dream* by Alexis Madrigal, the 33M-VS was designed between 1989 and 1993 by Kenetech and a consortium of electric utilities, and touted as a technological breakthrough.

"Unlike previous turbines, the 33M-VS is rigged to roll with the wind's punches. When gusts whip the rotor, the generator shaft is free to speed up in response. As the shaft's rotation speed changes with the wind, the alternating current that flows from the generator swings up and down in frequency. But between the generator and the utility grid lies an electronic power converter. This device first converts the variable frequency current to direct current, then switches back to alternating current at a fixed 60 cycles per second. So the generator feeds an even current to the utility grid. And the wind gust problems—wear and tear and wasted energy—have all but blown away." (*Madrigal, 2011, p.236*)

Kenetech Windpower was the original owner of the North American Patents for Variable Speed turbines. US Patent number 5,083,039 filed in 1992 and granted in 1993 (and its Canadian counterpart, dated one year later), staked a successful claim to the variable-speed operation of a wind turbine in conjunction with power electronics that provided multiple benefits. [*After the Kenetech bankruptcy in 1996, Zond obtained these patents. In acquiring Zond in 1997, Enron Wind gained access to the patents. And finally, after the Enron bankruptcy, this intellectual property fell into the hands of General Electric, where it resides today – although the primary effect of the patents lapsed in March 2010 in the US and March 2011 in Canada.*]

Wind turbines available in 1991 dominated by fixed speed

Company (current owner)	Model	Hub Height (m)	Rotor diameter (m)	Rating (kw)	Control – Power	Control – Speed
US Windpower (GE)	USW 56-100	18	17	100	Pitch	Fixed
Nordtank (Vestas)	NTK-150	32.5	24.6	150	Pitch	Fixed
Nordtank (Vestas)	NTK 450/37	35	37	450	Stall	Fixed
Micon (Vestas)	M530-250	30	26	250	Stall	Fixed
Vestas	V27-225	31.5	27	225	Pitch	Fixed
Vestas	V39-500	40	39	500	Pitch	Fixed
Bonus (Siemens)	150 Mk III	30	23.8	150	Stall	Fixed
Bonus (Siemens)	450 Mk II	35	35.8	450	Stall	Fixed

Source: adapted from cavello, 1993, p.83)

Energy conversion benefit

In the language of the filing, the advantages of variable-speed operation include "increased energy conversion and reduced stresses." In the long term, there was also a third benefit, that of "grid-friendliness."

As summarised by *Slootweg and DeVries, 2003*: "The advantages of variable speed turbines are that they generate more energy for a given wind speed regime, and that the active and reactive power generated can be easily controlled. There is also less mechanical stress, and rapid power fluctuations are scarce, because the rotor acts as a flywheel, storing energy temporarily as a buffer. In general, no flicker problems occur with variable speed turbines. Variable speed turbines also allow the grid voltage to be controlled, as

Variable Speed Enables WTGs to Hike Up the Power "Fall Line" Source: Baroudi et al., 2006

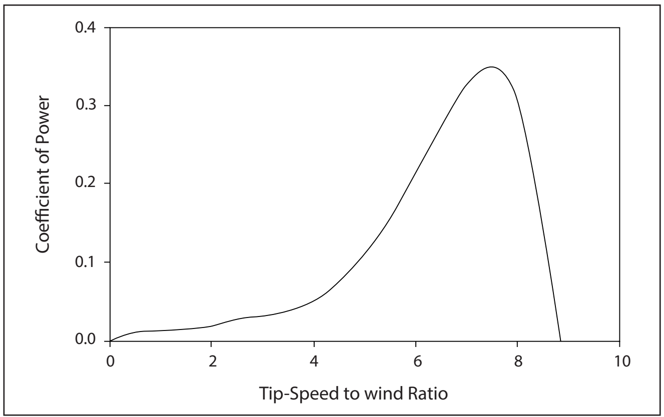


Fig. 1. Typical coefficient of power curve.

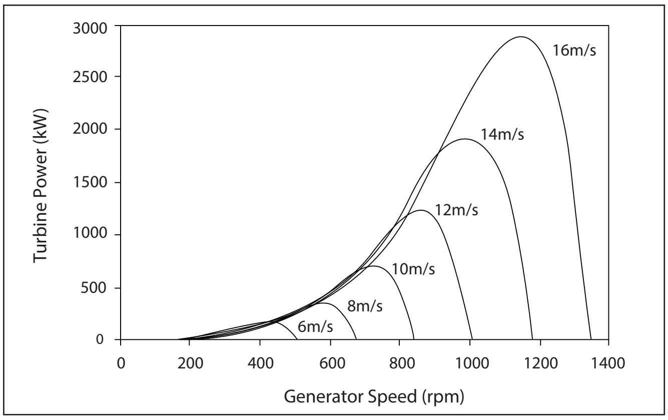


Fig. 2. Turbine output power characteristic.

the reactive power generation can be varied."

Varying the speed of the rotor generates more power over the course of a year by keeping the tip-speed near its optimum level. The VSPC machine will "on average collect up to 10% more annual energy." (*Carlin, Laxson, and Muljadi, 2001, p.5*).

In the case of the FSSC machine, as wind speed increases in the top diagram, tip-speed remains constant, which results in a suboptimal coefficient of power except at the maximum. The best a designer can do is aim for a wind speed that is "common," such as 7 m/sec. On the other hand, in a VSPC machine, tip-speed can vary, so the tip-speed to wind ratio can be kept near its perfect value, enabling the machine to climb the "mountain" in the lower diagram hitting each optimum along the way – "straight up the fall line," to use the mountaineering analogy.

One vivid example of the challenges of FSSC machines came from one of the interviews: "Optimising the machine for winter high season is completely different from summer high season. The air density goes way up in winter, so really the blade should be pitched differently but with those old machines, the blades did not move, so you had to pick one or the other. It was a hard decision, because even if the wind was somewhat lower in summer, the power prices were higher. Some people put it in the middle, and so got the worst of both worlds. But the most fun was had by the guys who went out and changed the blade pitch manually between winter and summer seasons!"

In addition to energy capture, the reduction of fatigue loads was also seen as a major improvement in reliability: "By allowing variable-speed operation there may also be a moderation of turbine rotor fatigue loads which are a major cause of machine failure." (*Carlin, Laxson, Muljadi, 2001, p.5*)

Kenetech demise

One might think that Kenetech would have capitalised on the strength of these amazingly important patents – but the story does not go that way. Kenetech seems to have overreached, tried to innovate in too many areas at once, and ended up with a highly unreliable machine that ultimately bankrupted the company:

"The 33M-VS was supposed to be less prone to failures thanks to its variable-speed rotor, and yet nearly every piece of the turbine was falling apart... Years later, wind industry insiders were still referring to the Kenetech fiasco." (*Madrigal, 2011, p. 247*).

Even the machines that survived gave their owners headaches. "Kenetech's legacy, and many of its machines, have lingered," Peter Asmus wrote in 1999. "But those who have worked with Kenetech's five-cent machines (the 33 M-VSs) say keeping them running can be hell."*(Peter Asmus, Reaping the Wind, p.188).*

So the 10% energy advantage of variable-speed was not only eroded by hybrid responses like two-speed operation and active-stall, it was also undermined by higher O&M cost. The early VSPC machines were seen as overly complex, high-maintenance machines. This was particularly important in the 1990s, because competent technicians were hard to find at the time.

"Presciently, (former Vice President of Engineering at Kenetech, Dr. Jamie) Chapman warned that turbine efficiency was only one aspect of the overall performance of a machine. Operations and maintenance costs could swamp the benefits of getting the 10% boost from the variable-speed rotor." (*Berger, Charging Ahead, 1998, p.1656*)

So, with flagging sales in a weak market and overextended on its warranty commitments, Kenetech finally went bankrupt in 1996. "Their old rival Zond bought their research on the variable-speed rotor on the cheap and (*Ed. - their successors*) developed a very successful turbine based on the technology." (*Madrigal, 2011, p. 249*).

Part 2 will be published in the May/June 2013 issue of Renewable Energy Focus. This will cover:

- Europe: Enercon Moves First, but Fails to Gain Lasting Edge
- The 1.5MW Platform: How GE Came to Dominate Wind Energy in North America
- Variable speed operation enables scale-up of wind industry

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