Fullerton Tsunami featuring the Fullerton Toroid C.V. Transmission

Design for Hydraulic Toroid Turbine Reliability

Fullerton Design has an extensive history in the concept of Toroid CV Transmissions covering over forty years, exhibited by the Analysis Report from Stanford Research Institute (S.R.I.) dated November 09, 1971(see in exhibits), as well as the first Toroid Patent, filed by Robert Fullerton, #3,727,474 and granted April 17, 1973(see in exhibits) also there are two existing prototypes, designed for other usage, that are for demonstration (see in exhibits).

Fullerton Design is, here, addressing two key issues that the wind power industry faces as it matures: instead of moving offshore and the use of bigger turbines as is the accepted thought, placing the turbine below the water surface, activated by tide, as well as providing power generation to off set the high cost of desalination. However, the clear focus must be on system reliability as well as environmental acceptance, which have become the number one design challenge that wind power generating market must address.

In addition to a technology focus on gearboxes and generators, we are looking at the entire drive train and how to use technologies such as gearbox health management tools, condition monitoring, ac brushless servo generators, and precision cooling systems to provide robustness, as well as serviceability that the next generation of this alternative energy demands.

Instead of focusing solely on the gearbox, as in the past, Fullerton Design is focusing on the complete electromechanical drive train business unit. If we look at the wind turbine drive train, from where the rotor shaft connects to the gearbox and on the other side where electrical energy comes out of the turbine, there are tremendous opportunities for boosting system reliability and serviceability while improving environmental impact.

Fullerton Design turbine design engineers are now taking a pragmatic approach on the need for reliability and serviceability in the drive train of offshore, as well as tidal turbines.

The focus is on larger wind turbines (4, 5, 7, and up, to 10 Mega Watts) developed for offshore operation and on ways to keep the drive train stable by deploying optimum conditioning and cooling for the various key components such as bearing, gearbox, generator and converter.

It is a well-known fact that if the bearings of a Toroid Units are well-lubricated, cooled with clean oil, have no moisture or humidity present, and employ a good filtration package, the Toroid Unit is less likely to fail. By monitoring the Toroid Unit using a new patentable concept of condition monitoring package (Fig. 1) that includes trends from temperature, pressures, vibration, cleanliness of the oil, and moisture issues we can reliably predict failure, or prevent failures, by knowing what will happen in the Toroid Unit over a time horizon.

The issue we might face, utilizing the Tsunami, or other “screw” drives in a fluidic environment is that it is not unlike formulating a scram jet flow rate and output.

You have input flow velocity (pressure of flow decreases as velocity of flow increases) going into the tube, pressures changing as the flow is translated across blade components and various blade angles, pressures and torque translations put back into the input, and final output pressures and flow (pressures increases as velocity decreases).

This will not include the “hydraulic knock” that will be due to thermal variances in the water that will occur from the water going from a cool “pipe “ to a warm “pipe” (sunshine to shade or, if the pipe is buried, cool earth to warm earth).

The translation rates, across these junctures will affect the efficiency of the drive; I'm speculating that a small input drive (controlling the input velocities) will be added by the output blade pressures, much the same as a conventional turbine engine however, the output controls the input not visa-versa; hydrodynamic calculus comes into play here to answer the question about pressures and where.

The CVT Transmission will be able to compensate for these variances eliminating the possibility of run away vibration sine waves that wound be catastrophic in such a closed environment.

This is all do-able.

With the trend moving toward larger turbines and offshore applications because of the availability, and consistency, of the wind an important focus will be on the serviceability and service intervals of these offshore installations. This is driving suppliers to better control of the temperatures in the now used gearbox and to the optimization; as well as monitoring of the cleanliness of the oil in the system. To get service people on board, in an offshore turbine, it normally means you need a ship or helicopter. As a result, suppliers are improving the lubrication systems and increasing the lifetime of the filters so it has a maximum of once a year to service the unit; and sometimes the service interval is increased to 18 months.

Users can employ an online connection to assess when they need to schedule maintenance on the turbines. Some of these systems constantly measure the pressure differential over the filter element and communicate the information over industry-standard electronic protocols that can be accessed remotely. With ability to program these devices, reaching a threshold of pressure level indicates when it is time to change the element. Remote monitoring also allows for preventative and scheduled maintenance events that reduce the cost of service. Not a problem with the Fullerton Toroid Unit.

Fullerton Design will also offer systems to monitor the condition, as well as the temperatures, of the Toroid Unit lube oil with respect to the amount and type of possible contamination in the bearings or Toroid Unit. If everything is running smoothly, and there is no extensive wear on the bearings, it is normally OK to use an 18-month service interval but, performance is also dependent on the Toroid Unit itself, vibration, alignment, loads and other factors.

Fullerton Design introduced modularity into the system. So instead of using one large filter we are specifying two or three optimum size and mesh filters outboard filter/cooler units (Fig. 2) to the Toroid Unit lubricating system to better perform service and further condition the oil while keeping pressures consistently low in the system. The lifetime of the components is vital along with serviceability. It is known that, in many gearboxes, people are using a lot of connectors and hoses to connect different components, which mean there is always a possibility for leakage; not to mention the drop in efficiency of the package. This is eliminated in the Fullerton Concept.

Fullerton Design's approach to these applications is to integrate multiple functions into a patented uni-package, which combines the process and the control parts of the total system, plus optional functions including bypass filtration if that is needed (Fig. 3).

A third important area is condition monitoring. Normally, if there is any oil condition monitoring at all in these systems, it is metal residue monitoring - which means that only the large metal particles are monitored; not for size but for count.

We know that if it produces a lot of smaller particles before the big particles start to appear, a system is starting to degenerate. By automatically measuring particles that are 100 microns or bigger we will start trending micrometer-sized particles, which the human eye can't see. When the selected amount of particle contamination is reached an electrical connection is automatically made; providing notice of mechanical metal wear. With the systems used today you almost need dedicated laboratory equipment to view particles of this size this is eliminated with the Fullerton Design Micron electrical switch (Fig. 4).

Fullerton Design will introduce new tools for this type of monitoring and develop a system to do this online with the Toroid Unit without taking samples to a lab. The key is that measurements can be trended on a continuous basis and specific commands can be used to prevent further damage or optimize the use of the filtration system.

Trend to AC Brushless Servo Motors

The key in wind turbine applications is reliability and availability, which means the wind turbine, must be available to produce energy whenever there is wind. The challenge for the Fullerton Design system is to make sure that components are reliable and robust enough to support that environment which means balancing features, performance, and cost while providing a system that is, for all intents, invisible to the public as well as being non offensive to the environment.

The present day “wind mill” is equipped with an electric pitch control systems, typically located in the rotating part of the turbine (hub) and include one rotary actuator (electric motor and gearbox) connected to each blade. Power and control electronics allow the motors to develop the right torque and follow a motion profile provided by the turbine controller. A power back-up system allows the motors to bring the blades into a safe position, even in case of power loss, and a set of encoders (one per blade) supplies blade position feedback. This also is not necessary, in the Fullerton Concept, of providing a simpler mechanical device.

With wind turbine applications, whether they are offshore or not, the environment is harsh because system components are essentially outdoors within a hub that is not weatherproof. Ambient operating temperatures range from extremes of -40 to 50C. This means that the actuators and motors need special attention paid to sealing, and the ability to meet performance requirements throughout the full temperature range. Again not required in this Fullerton Concept.

The rigorous environmental conditions on the concepts in use today apply to the controls as well, plus all of the components in the control cabinet. Up in the moving rotor as well, the system must be designed to withstand the vibration and shock of it being continuously rotated. Reliability is key, because the motion system functions as the key safety system of the wind turbine. Not a concern with this Fullerton Concept.

The concepts in use today all focus on supplying highly reliable integrated electric pitch systems to the wind industry. Even though they will offer pitch systems, using different types of motor technologies (dc brush type motors, ac induction motors and ac brushless servo motors), the focus is on systems using alternating current brushless servomotors.

Traditionally, dc motors have been applied to pitch systems; but there is a current trend to applying more ac synchronous motors to eliminate the brush failure mode.

Throughout the rest of industry, and aerospace applications, there is a general belief that ac motors are inherently more reliable, even though they haven't been widely accepted in the wind industry yet. A problem; not associated with the Fullerton Concept.

Fullerton Design is in the process of developing Digital signal controllers to enable drives for permanent magnet synchronous generators to be optimized with complex algorithms at low cost.

A permanent magnet synchronous generator (PMSG) provides very good efficiency because of its constant rotor magnetic field, which is produced by a permanent magnet on the rotor. In addition, its stator magnetic field is generated by sinusoidal distribution of the windings. Compared to induction generators, PMSGs have a very high power/size ratio. They also produce less electrical noise compared to dc generators since brushes are not used.

In PMSG-based appliances, field-oriented control (FOC) offers a great cost benefit because it eliminates the position sensors. The sensor less FOC technique also overcomes restrictions placed on some applications that cannot deploy position or speed sensors, such as those in which the generator is immersed in oil. Although proprietary FOC designs using ASICs are available, a new generation of digital signal controllers (DSCs) offers a low-cost alternative for implementing the FOC algorithm.

DSCs are suitable for this use because they feature peripherals tailored for generator control such as pulse width modulators (PWMs), analog-to-digital converters (ADCs) and quadrate encoder interfaces. When executing controller routines and implementing digital filters, DSCs help designers optimize code execution by being able to carry out the multiply-accumulate instructions and fractional operations in a single cycle. Also, for operations requiring saturation capabilities, DSCs help designers avoid overflows by offering hardware saturation protection.

DSCs need fast and flexible ADCs for current sensing, a crucial function in generator control. For example, the Microchip dsPIC DSC family features ADCs capable of converting inputs at a 1-Msample/sec rate and handling up to four inputs simultaneously. Multiple trigger options on the ADCs enable the use of inexpensive current-sense resistors to measure generator phase-winding currents. Triggering ADCs with PWM modules enables inexpensive current-sensing circuitry, by sensing inputs at specific times where switching transistors allow current to flow through the current-sense resistors.

Development Tools

The FOC generator-control firmware discussed in this writing was developed based on Microchip's dsPICDEM MC1 Motor Control Development Board.[1] Microchip's data monitor and control interface (DMCI) tool, which is a module within the MPLAB Integrated Development Environment (IDE), was used to test and debug the FOC algorithm. The DMCI tool provides a quick and dynamic IDE, which allows designers to graphically represent the application feedback. For instance, DMCI's IDE provides project-aware navigation of program symbols (variables) that can be dynamically assigned to any combination of slider, direct input or Boolean controls. These controls can be used interactively to change the values of program variables within the DMCI IDE. Further, the graphs can be dynamically configured for viewing program-generated data.

In the system overview block diagram (**Fig. 1**), it can be seen that no position sensors are attached to the generator shaft. However, there are some sensors used for current measurements on the generator. These sensors feature low-inductance resistors that are part of the inverter function block. A three-phase inverter stage drives the generator windings (**Fig. 2**).

The FOC Algorithm

The following is a step-by-step summary of the FOC (or vector-control) algorithm:

1. Measure the stator currents phase currents i_A and i_B. Calculate i_C from the fact that $i_A + i_B + i_C = 0$ and calculate the currents from the two current sensors.

2. Convert the set of these three-phase currents onto a two-axis system. This conversion provides the variables i_α and i_β from the measured i_A, i_B and i_C values; i_α and i_β are time-varying quadrature current values, as viewed from the stator's perspective. This step is called Clarke Transformation.

3. Rotate the two-axis coordinate system to align with the rotor flux, using the transformation angle calculated at the last iteration of the control loop. This conversion provides the i_D and i_Q variables from i_α and i_β. Now, transform the quadrature currents, i_D and i_Q, onto the

rotating coordinate system. During steady-state conditions, i_D and i_Q will remain constant. This step is called the Park Transformation.

4. Error signals are formed using i_D, i_Q and reference values for each. The i_D reference controls rotor-magnetizing flux. The i_Q reference controls the torque output of the motor. The error signals are input to proportional and integral (PI) controllers. Then, the PI controller's output provides V_D and V_Q, which is a voltage vector that will be sent to the motor.

5. Estimate the new coordinate transformation angle, where V_α, V_β, i_α and i_β are the inputs. The new angle guides the FOC algorithm as to where to place the next voltage vector.

6. Rotate the V_D and V_Q output values from the PI controllers back into the stationary reference frame, using the new angle. This calculation provides new quadrature voltage values, V_α and V_β.

7. Transform the V_α and V_β values back to three-phase values V_A, V_B and V_C. The three-phase voltage values are used to calculate new PWM duty-cycle values that generate the desired voltage vector. The entire process of transforming, PI iteration, transforming back and generating PWM is shown in Fig. 3.

Sensor less FOC for PMSMs

The sensor less control technique implements the FOC algorithm by estimating the position of the generator without using speed or position sensors. **Fig. 4** shows a simplified block diagram of the position-estimator function. The FOC algorithm is executed at the same rate as that of the PWM duty-cycle algorithm. In the FOC algorithm, the PWM triggers two respective ADC conversions for the two winding-current shunt resistors. Then a potentiometer is used to set the reference speed of the motor. The ADC interrupts generate the data samples needed to execute the algorithm.

From the motor model in **Fig. 5**, the input voltage can be obtained:

And solving for i_S gives the motor current: where i_S equals motor current vector, v_S equals input voltage, e_S equals back-EMF vector, R equals winding resistance and L equals winding inductance. In the digital domain, this equation becomes: Again, solving for i_S yields:

Current Observer Model

A current observer model enables the indirect measure of the back EMF by ensuring that the input to the system (generator) is equal to the input to the generator model. Here is how it works: The generator and generator model is fed with the same input, but the generator model has a closed-loop controller to ensure that the estimated value matches the measured value. For example, at any given time, if the actual generator input voltage and current are the same as the model, then we can "observe" the back EMF by solving for e_S.

For the observer model compensation, a sliding-mode controller can track the input reference and force the error to zero between the measured current i_S and the estimated current $i_{SESTIMATED}$. Depending on the error sign, the sliding-mode controller will apply either a positive feedback gain (K) or a negative feedback gain (-K) to get the estimated current to match the measured current. Because the input voltages are the same for both the generator and its model, the back EMF can be calculated when the estimated and measured currents match.

Back-EMF Estimation

Once the input currents and voltages of the model and the actual generator match, the correction factor z from the generator model can be filtered to get the back EMF. For this step, we use a first-order digital low-pass filter, with the equation:

To filter z to get $e_{SESTIMATED}$, we substitute the value of f_{PWM} in the equation below:

Where e [n] equals the next estimated back-EMF value, e[n-1] equals the last estimated back-EMF value, f_{PWM} equals the PWM frequency at which the digital filter is being calculated, f_C equals the cutoff frequency of the filter and z[n] equals the unfiltered back EMF, which is output from the sliding-mode controller.

Solving this equation for e[n] yields the updated back-EMF value. The value of the cutoff frequency can be determined through trial and error, depending on the selection of the sliding-mode controller gain. The relationship between back EMF and the rotor's updated position is given by:

Speed Calculation

Due to the filtering function applied during the theta calculation, some phase compensation is needed before the calculated angle can be used to energize the generator windings. The amount of theta compensation is dependent on the rate of change of θ_{ROTOR}, or the speed of the motor (ω_{ROTOR}). The compensation for θ_{ROTOR} is performed in two steps: First, the speed of the motor is calculated based on the uncompensated theta calculation; second, this speed is used to calculate the amount of compensation. Summing θROTOR values over M samples, and then multiplying the summed values by a constant can calculate the speed. This is given by:

Where ω_{ROTER}[n] equals angular velocity of the motor, θ_{ROTOR}[n] equals current rotor position value, θ_{ROTOR}[n-1] equals previous rotor position value and K equals amplification factor for desired speed range.

Generator Startup

Because the sensor less FOC algorithm is based on the back-EMF calculation, the generator needs to run at a minimum speed to get the back-EMF value. Therefore, energizing generator windings with the appropriate estimated angle is required. To handle this, a motor startup subroutine was developed and works as follows: When the generator is at standstill, and with the start rotation begins, the dsPIC DSC generates a series of sinusoidal voltages to set the generator spinning. While the generator spins at a controled acceleration rate, the FOC algorithm controls the currents i_D and IQ. The value of θ is incremented based on the acceleration rate.

Software State Machine

It is helpful to visualize the FOC algorithm as a software state machine (**Fig. 7**). First, the generator windings are de-energized and the system awaits rotation. Once the rotation begins, the system enters the initialization state where all variables are set to their initial value. Then, the startup subroutine is executed. The current components for torque (i_Q) and flux production (i_D) are being controlled by the FOC, and commutation angle (θ) is being generated in a ramp fashion, to get the motor spinning and reaching the minimum speed required to run the estimator.

After going through the startup subroutine, the system switches over to sensor less FOC control, where the speed controller is added to the execution thread, and the sliding-mode controller (SMC) starts estimating θ, as previously explained.

Upon entering the sensor less FOC control state, the reference speed is continuously read from an externally connected potentiometer, and the shaft RPM is also monitored to determine efficiency.

In addition to the RPM being obtained while the shaft is beginning to rotate, any fault in the system will cause the generator to stop and return to the “generator stopped” state. The generator remains stopped until the system is checked and the problem corrected preventing damage.

DSC-Based FOC Control

A major advantage of deploying DSCs in generator control will be the practicality of a common design platform, which can lower production costs. This means we will now have an economical way to offer a range of design models that use PMSMs, or other generator types, with sensor less FOC algorithm control. These software-based generator-control designs enable rapid customization to address multiple applications.

Firmware IP protection will be a major issue for this design team. Engineer teams based in different locations could work in tandem to implement FOC firmware, develop the appliance front panel and complete the final system integration. Furthermore, in developing their designs, these teams will generate their own IP. Microchip's dsPIC DSC family offers the Code Guard feature,[2] which helps to protect IP in collaborative design environments by securing IP segments separately.

Since programming DSCs is similar to programming microcontrollers, the design team can quickly design their motor-control algorithm and test their prototypes. Best of all, fine-tuning the motor control has been simplified through the use of IDE-based tools such as the DMCI, which allows designers to easily port their algorithms across a variety of generator platforms on a proprietary basis.

It must be noted here that most of the above, though commonplace with motor usage, is not, until now in use with this type of generator. It is the opinion of Fullerton Design that their new concept of generator and accessories will be new, novel and of a proprietary concept.

Differential Gearboxes

The trend in the wind industry we have seen is a continuing move toward larger-size turbines. Until last year, the most common size installed in the U.S. was 1.5 megawatts. But, the trend is larger and larger systems and turbines in the 2 to 2.5 megawatt range will be more or less a standard for onshore wind turbines over the next several years. The larger units now in service as well as on the design board only emphasize the claims of the critical environmentalist whereas the Fullerton Design Toroid Unit will overcome this visual blight by not being visible.

“The concept that Fullerton Design is targeting is multi-megawatt turbines. It is slender and compact, due to its CVT Toroid design concept with two planetary stages.

A clear trend is more systems going offshore, or actually "near shore", where they are typically installed between three to five miles off the coast. The advantage is a smooth flow of wind, the turbine is not in anybody's backyard, and the noise issue is gone. For all those reasons, wind turbines are moving to offshore locations, but a major problem is regular periodic maintenance, which has the potential to become prohibitively expensive; this is overcome with the Fullerton Design Toroid Unit.

Because of quality, and reliability issues, people are talking about using a direct drive system rather than a gearbox for large offshore applications, We see some benefits in that but, by the same token, with developments to increase reliability and improved quality, we believe you can have a very good solution with a Toroid Unit in the system even up to 5 or 6 megawatts using the constant motion of the tidal action providing an efficient, silent, usage.

With the demand for higher power density and compactness growing, Fullerton Design’s Toroid Unit offers more compact drives and minimizes the weight by providing a multiple power-split Toroid Unit design solution with out the danger of “blade collision” with human or wild life.

Unlike conventional generator gearboxes in the multi-megawatt class four, or more, planetary gears do not revolve around the sun wheel in the input stage. Instead, the Fullerton Design concept offers two input stages, each fitted with three planetary toroidal rollers sandwiched between two toroid disks, and the advantages of a static determination paired with freely adjustable sun pinions; providing a continuous current flow with out concern of wind velocity.

Another key design feature is a thin outer diameter, with only a slightly greater total length. With turbine capacities increasing, it offers up to a 15 percent weight advantage over gearbox concepts currently in use without a decrease in reliability.

There have been tremendous improvements, in terms of planning and doing preventative maintenance rather than repairs after a catastrophic failure. Along with the trend toward larger turbines, typically located offshore, there is a rise in condition monitoring solutions that enable users to predict, and plan for, maintenance.

Lubrication is the key to the reliability and operating life of gearboxes, and this applies in particular to gearboxes for wind energy plants, due to the difficult conditions in which they operate. This is why Fullerton Design is offering main CVT units featuring their own cooling lubrication system with particle monitoring and water content sensors.

While engineers are generally concerned about the reliability of the gearboxes, often what actually limits bearing life is lubricating fluid, or oil, which becomes too dirty or too hot. The push to condition monitoring is one way to manage these important assets.

We believe we have eliminated most, if not all, of these concerns.

Comparing the standard “Wind Turbine” to the Tsunami

The Wind Turbine

They can’t replace all of our existing power plants, but they are, until now, an attractive supplement that provides renewable energy. If we want to compete with these machines, though, we first need to understand how they work.

A Couple Of Unknowns

It is clear that the impacts of this technology might not be completely understood. There are many claims of low-frequency noise. Perhaps that repetitive low-frequency “whoosh whoosh” sound is the culprit; perhaps also is it the “bird kill “ factor, not to mention the “visual blight”.

There is lacking substantive research for or against this theory, such as a weighted sound pressure level meter, to actually show the Decibels (dB) range of the operation

If the rotor has three blades spinning at 10 rpm or so, the whooshing is happening 30 times a minute or at 0.5 Hz. This fundamental is more than 160 dB.

The hundredth harmonic of this fundamental noise is at 50 Hz, which is still 32 dB.

Another question that pops up is that of the long-term impact on wind and weather patterns. Again, this sort of study takes a lot of time and instrumentation—perhaps millions of sensors and a couple of decades of measurement. Such studies won’t bear any fruit in the fiscal quarter in which they are paid, purposed, and accounted for, so they likely will be overlooked.

Unknowns aside, then, we have to ask what’s in that box and how it works.

How Do They Work?

When we drive past these majestic machines or perhaps inquisitively walk up to them, we see their big blades spinning slowly in the prevailing winds. The rotor couples to the nacelle. All of the necessary equipment to transform this mechanical energy flow into electrical power is inside the nacelle.

There are two types of nacelles in the Midwest: the more popular, elongated, and somewhat streamlined “shoebox” nacelle and the truncated, shorter, rounded cone “clipper” nacelle. I don’t have much experience with the clippers, since I haven’t found a way to have a close look at them yet.

The easiest place to start exploring the shoebox nacelle is at its rotor. If we look at a Gamesa G90 machine, we see that the electrical output power at max wind is 2 MW. This occurs at a rotor speed of 19 rpm. The gearbox in the machine multiplies this shaft speed up by a ratio of 120:1 to run the generator in the rear of the machine.

The super-synchronous, doubly fed induction generator (SSDFIG) in the rear of the machine produces this power level at 690-V, three-phase output. On paper, that’s hardly amazing, but when you approach the machine, it’s quite spectacular. The blade diameter is 295 feet. This means the swept area is roughly 68,500 square feet or 1.6 acres. That’s substantial!

The power train comprises a rotor, cascaded with a gearbox, cascaded with an SSDFIG. If the output of the SSDFIG is 2 MW, the input is certainly larger. Little information is available on the losses in the gearbox and SSDFIG, but both of them have substantial cooling mechanisms, so they aren’t near the ideal.

In the absence of any data let’s ballpark them at a throughput efficiency of 85% each. If we cascade these stages, we then need a mechanical input of 2.768 MW at the rotor. With each of the three blades properly pitched to create full power in full wind, and a rotor speed of 19 rpm, the rotor then sees a total torque of roughly 1 million foot pounds. And that's just steady state. What about wind gusts? Indeed, they're a prime mover where the power train is located 325 feet above the ground.

The Gearbox

Looking at the power train components, one has to ponder the gearbox: 1 million-foot pounds of torque input! The gearboxes are typically planetary arrangements, often set up in two or three stages. The gearbox weighs between 40,000 and 60,000 pounds depending on the machine. Lubricants found in the gearbox are usually on the order of SAE 360, equipped with heaters (to keep the lubricant viscous on cold inactive days) and pumps, radiators, and fans to carry the heat away from the gearbox.

Gearboxes are the main point of failure. Anyone that has had experience with performance cars knows that very high torque is tough on gears!

The SSDFIG converts the mechanical power into electrical power. First, "SSDFIG" includes the term "super synchronous" because the induction motor is operated in a negative slip. The shaft is spun faster than the locked synchronous speed, generating electricity at line frequency.

Next, it includes “doubly fed” because the machine is fed from both the rotor and stator. The conventional shorting bars in the rotor are broken on one side and connected to slip rings. In simplest form, adding resistance to these slip rings changes the negative slip of the machine, allowing a larger range of shaft speed to result in line frequency output.

The shiny load bank on top of some of the nacelles is the resistor bank used to add the slip. Beyond this, additional control techniques are employed wherein ac current is injected into the rotor to control reactive power. This is typically done with an IGBT-based (insulated gate bipolar transistor) inverter and a torque vector control. This is not a trivial task.

If we consider the rotor of an induction motor, the frequency of current in the rotor increases as the motor is loaded. If the machine stalls, the frequency of current in the rotor is that of the line. We can flip this across the synchronous speed axis and say it’s similar for an induction generator. To generate anything, the rotor has to be spun faster than the rotating fields in the stator.

If it is stalled, generating nothing, the drive that processes the power, waveforms, and phasing into the rotor has to handle full transformer action. Those voltages can be substantial. Further, maximum output of these machines requires rotor currents on the order of 1000 A. Whether steering into a resistive load bank to simply add slip or driving appropriate excitation and phasing to control power factor, the control needs to safely accommodate these currents

Most anyone who has stalled a table saw or a bench grinder has developed a good feel for the torque/speed characteristics of an induction motor. The turbine's induction generator is similar, except it generates power.

Finally, the induction generator in the SSDFIG is a three-phase induction machine overexcited to operate as a generator.

The SSDFIG typically is air-cooled and requires a fair amount of ventilation. I've read about multiple blowers on the order of 20 hp per unit. A typical insulation system for an SSDFIG is a class F or B system with a maximum ambient temperature of 40°C. The intake for the blowers is on the bottom or rear of the nacelle, and the exhaust is on the top.

Additional Actuators

In addition to the primary power train, a couple of other actuators merit discussion. The rotor blade pitch control is one of the most interesting. Its function is pretty straightforward. Each of the three blades needs to be rotated to proper pitch for the wind input and power output conditions. Various position encoders maintain the same pitch for all three blades.

The machine of choice to do this is an induction motor with a substantial gear head and a variable frequency drive. The gear head mates with ring gears on the rotor blades. That's easy enough to understand. The interesting part arises when we consider that the rotor spins, which isn't very eventful. Gear head motors and drives can handle that without much trouble.

The required operation compounds these needs. In the event of a power outage, the rotor blades must pitch full into the wind. So, a battery bank is needed to run the drives in the event of power failure. The battery pack has to rotate in the rotor as well. While most sealed battery chemistries appear to be able to do this, few are rated for the job.

The pitch information, power source (as available), and command come in through slip rings on the rotor. While the drives in the rotor are quite secure in a 1-in. thick steel faraday cage, the slip rings and related wire harness are fairly susceptible to lightning events. Lightning often hits the highest blade. The current is earthed through conductors in the blade that tie to the rotor.

We certainly wouldn't want that 10-kA to 100-kA current impulse flowing through the bearings and the races, so sharp and pointy spark gaps near the rotor arc over and conduct this current to earth ground. While fairly deterministic, all of those lines are certainly near that lightning event. The good news is that they usually tie into the controls toward the rear of the nacelle, not in the shortest earthling path, but they still see some energy and failures from these events.

The yaw position motors like the rotor position motors. They are slightly larger and often operated as multiple units in parallel, but they are induction machines with gear heads nonetheless. Nearly all large-scale wind turbines that I'm aware of control yaw so the blades are on the windward side and the wind then flows over the nacelle.

Wind Turbine Classifications

Three main categories.

Type III machines are used in low-wind areas, defined as an average wind speed at the height of the rotor hub of 16.8 mph. These machines stand a little taller and have blade diameters slightly larger than the remaining classes of machines. Type II machines are used in medium-wind areas with an average wind speed of 19.0 mph at the height of the hub. Type I machines are used in high-wind areas with an average wind speed of 22.4 mph or greater. The classifications bear no correlation to maximum output power.

THE UNDERWATER TSUNAMI USED IN OCEAN TIDAL LOCATIONS

Thanks to recent advancements in technology, tidal power is starting to gain recognition as one of the future's most promising forms of renewable energy. With the bulk of the world's population living on ocean seaboards or close to flowing water, the World Energy Council estimates that harnessing the kinetic energy of oceans and rivers could supply the world's electricity demand twice over.

The world's oceans.

Due to the strong attraction to the oceans, a bulge in the water level is created, causing a temporary increase in sea level. When the sea level is raised, water from the middle of the ocean is forced to move toward the shorelines, creating a tide. This occurrence takes place in an unfailing manner, due to the consistent pattern of the moon's orbit around the earth. The magnitude and character of this motion reflects the changing positions of the Moon and Sun relative to the Earth.

Tidal power is the only technology that draws on energy inherent in the orbital characteristics of the Earth- Moon system, and to a lesser extent in the Earth–Sun system. Other natural energies exploited by human technology originate directly or indirectly with the Sun, including fossil fuel, conventional hydroelectric, wind, biofuel, wave and solar energy.

Nuclear energy makes use of Earth's mineral deposits of fissionable elements, while geothermal nuclear taps the Earth's internal heat, which comes from a combination of Residual heat from planetary accretion (about 20%) and heat produced through radio active decay (80%)

Because the Earth's tides are ultimately due to gravitational interaction with the Moon and Sun and the Earth's rotation, tidal power is practically inexhaustible and classified as a renewable energy source resource. Movement of tides causes a loss of mechanical energy in the Earth–Moon system: this is a result of pumping of water through natural restrictions around coastlines and consequent viscous dissipation at the seabed and in turbulence. This loss of energy has caused the rotation of the Earth to slow in the 4.5 billion years since its formation. During the last 620 million years the period of rotation of the earth (length of a day) has increased from 21.9 hours to 24 hours; in this period the Earth has lost 17% of its rotational energy. While tidal power will take additional energy from the system, the effect is negligible and would only be noticed over millions of years.

Unlike wind and solar, tides are predictable, dependable and powerful. The gravitational pull of the sun and moon regulating the ocean's currents works like clockwork. It is well known that water is 800 times more energy dense than wind and marine technologies have two to three times the capacity factor of solar. Though all forms of renewable energy have a place in the global energy mix, those that are dependent on weather conditions won't be enough to compete with more reliable fossil-fueled sources of power.

The whole global economy is based around reliable, continuous power, Energy sectors that are dependent on the weather are very unpredictable and difficult to integrate into the electrical systems being used around the world today.

The Tsunami concept, while using ocean energy will not power everything; it will function in tandem with other renewable resources and supplement other seabed technologies.

The energy potential of tidal basins is large- the largest facility, the LaRance station in France, generates 2450 MW of power.

The Tsunami concept could be installed and operate any were in the world.

It will make no noise, is almost, if not completely below the surface, never run out of operating energy and has zero emissions.

Designed to exploit the underlying principle and raw power of an ocean whirlpool, the technology harnesses up to four times more power and is up to 70 percent more efficient than conventionally used propeller (air drive) models on the market. The composite materials used to construct the device will have a life of 100 years in salt water and hold a competitive advantage to other commonly used materials.

Composites, in my view due to many years involvement with building performance cars, are a superior material to work with when talking about deploying things in the ocean. We will use a material that can be molded to any shape, which gave us much more flexibility in developing an exotic design.

Growth in offshore wind has already demonstrated that despite the unforgiving marine environment, energy can be harvested offshore. Yet, the same sized turbines used to capture wind can generate up to eight times more power from ocean currents, tides and rivers. The Tsunami will be more compact than wind turbines, making it easier to transport and set up - minus the visual and noise pollution that comes with hillside wind farms, you cannot see what is 30-50 feet below the ocean surface.

Scalable from 300W to 2MW in size, the device is deployable in the largest range of ocean and river locations around the world. One large Tsunami will produce enough energy to power 1,000 homes.

That's another one of our advantages. We can put multiple small units to aggregate to a large number, giving us much more flexibility to deploy the technology to a lot more locations.

One thing is clear: tidal power is one of the largest and reliable forms of renewable energy suitable for integration into base load grid systems, yet one of the most untapped. Technology is changing that, giving way to a whole new industry we're about to see become a huge part of the renewable market in the very near future.

That's another one of our advantages. “We can put multiple small units to aggregate to a large number, giving us much more flexibility to deploy the technology to a lot more locations.”

But enough of this complicated effort that will take time in engineering. There is low hanging fruit that can be taken now with out having to worry about permits, building complicated structures etc.

There is, at this time, a problem in California as set forth in this article below, condensed to fit in this document.

Desalination Plant in California

Besieged by drought and desperate for new sources of water, California towns are ramping up plans to convert salty ocean water into drinking water to quench their long-term thirst. The plants that carry out the high-tech "desalination" process can cost hundreds of millions of dollars, but there may be few other choices for the parched state.

Where the Pacific Ocean spills into the Agua Hedionda Lagoon in Carlsbad, Calif., construction is 25 percent complete on a $1 billion project to wring 50 million gallons of freshwater a day from the sea and pour it into a water system that serves 3.1 million people.

Desalination was a dreamy fiction during the California Water Wars of the early 20th century that inspired the classic 1974 movie "Chinatown." In the 1980s, however, the process of forcing seawater through reverse osmosis membranes to filter out salt and other impurities became a reliable, even essential, tool in regions of the world desperate for water.

The process, however, is energy intensive and thus expensive, making it practical only in places where energy is cheap, such as the oil-rich Middle East. But recent technological advances in membrane materials and energy recovery systems have about halved the energy requirements for desalination, giving the once cost-prohibitive technology a fresh appeal in a state gripped with fear that it may be in the early stages of a decades-long mega-drought.

"I think it will turn out that it is very affordable compared to not having the water here in Southern California, particularly with the drought that we are facing and the fact that the governor has just cut off the flow of water from north to south in the aqueduct, the State Water Project," Randy Truby, the comptroller for the International Desalination Association, an industry advocate, told NBC News.

The multibillion-dollar State Water Project is a complex conveyance system that brings water from the wetter northern part of the state to farms, industry, and people in the thirsty south. In times of drought, such as now, banking on that water is a risky bet.

San Diego's $1 billion bet.

In the early 1990s, fears that a drought-induced limit to imported water could leave San Diego County with just a trickle from its scarce local supply prompted the regional water agency to include desalination as part of its long-term strategy, according to Bob Yamada, a planning manager with the San Diego County Water Authority.

Today, the county's Carlsbad Desalination Project under construction is the largest seawater desalter in the Western Hemisphere. When it comes online in 2016, the $1 billion facility will produce enough water to meet the daily needs of 300,000 area residents, which is about 7 percent of the county's water requirements.

That's water, the project backers say, that will no longer have to be imported via the Metropolitan Water District of Southern California, a wholesaler of imported water based in Los Angeles that has a testy relationship with its southern neighbor.

But that dash of independence comes at a cost. The water authority is locked into a 30-year deal with the plant's developer, Poseidon Water, to purchase desalted water for about $2,000 an acre foot in

2012 dollars. That's nearly twice as expensive as the current rate for imported water and will add $5 to $7 per month to ratepayers' bills, which is about a 10 percent hike.

The county is making the bet "that even though there is a significant difference right now, those costs will converge in the future [and] that convergence could happen as soon as the early 2020s," Yamada told NBC News. He added that water authority studies found that 68 percent of ratepayers are willing to pay more for a drought-proof water supply.

Cost and environmental concerns.

"The trend of imported water (pricing) is definitely going up," Heather Cooley, co-director of the water program at the Pacific Institute, an Oakland-based environmental think tank, told NBC News. "We have some major infrastructure investments needed for imported water in California. I don't have a crystal ball for what it is going to look like, but no doubt it will raise the price of imported water."

The pending price hikes for imported water as well as its uncertain reliability, she explained, are compelling reasons for municipalities to consider desalination. But, she noted, "we can't look at these issues in a vacuum; we have to look at all the options that are available."

The sentiment is echoed by the San Clemente, Calif.-based Surfrider Foundation, which has opposed several desalination projects, including Carlsbad, on environmental grounds. For example, sucking up large amounts of seawater can kill fish and other creatures as water passes through intake screens.

"Our general position is there is just a lot more that can be done on both the conservation side and the water recycling side before you get [desalination] and we feel, in a lot of cases, that we haven't really explored all of those options," Rick Wilson, the organization's coastal management coordinator, told NBC News.

Mothballed in Santa Barbara

A reconsideration of desalination is underway in Santa Barbara, about 185 miles north of Carlsbad, where planners are in the early discussions about investing around $20 million to upgrade and restart a$34 million desalination plant that was constructed there in the early 1990s as a hedge against an ongoing drought, according to Joshua Haggmark, the interim water resources manager for the city

The Charles Meyer Desalination Facility in Santa Barbara, Calif. is something of a time capsule from the early 1990s when it was completed at a cost of $34 million. It only operated for a few months and has remained dormant for over twenty years. Now the city of Santa Barbara is considering restarting the aging desalination plant to deal with the state's drought.

Although the plant was permitted and constructed in just two years, it was never brought online. The rains returned and filled area reservoirs just as the desalter was completed. "It was really a challenge to continue and run and operate the facility given the much cheaper surface water," he told NBC News. "The facility was mothballed. " In fact, part of it was disassembled and sold to Saudi Arabia.

Bringing it back on line will require a massive overhaul. What's more, "Santa Barbara is a pretty topographically challenged community; there are quite a few different elevations," Haggmark said. Most of the coastal city's water comes via gravity from higher elevation reservoirs. Desalination "comes in at the bottom. You have to lift this water and move this water further up into the system, which is expensive."

Once infrastructure is factored in, the desalinated water would cost Santa Barbara about $3,000 per acre-foot. The facility currently has permits to operate at 3,125 acre-feet per year, which "would basically replace what we are currently getting out of the State Water Project," Haggmark said.

Sand City Independence

Limited water resources on the Monterey Peninsula hindered master development plans for the small town of Sand City, Calif., which was restricted from any new construction until the city increased its water supply. Regional efforts to find solutions ran into financial and political constraints for more than 20 years. Frustrated, the city struck out on its own to develop a desalination plant.

The city partnered with California American Water for the $14 million project, which started producing 300 acre-feet of freshwater a year in 2010. The plant draws brackish water from wells, which is less salty than seawater, meaning its energy requirements are less. The salt content of the leftover brine is about equal the oceans, so it can be discharged without damaging the marine environment.

The city currently uses about a third of the annual output; the rest is shared among other cities on the water-short peninsula. This allows the water company to reduce its reliance on the stressed

Carmel River, which is under state protections.

"Our plant has two benefits, we brought our own water and also we allow the water company to reduce pumping from the illegal source," Sand City Mayor David Pendegrass explained to NBC News. To further alleviate pressures on the river, American Water is pursuing a larger desalination plant on the Monterey Peninsula.

Ultimately, she said, seawater desalination will become part of the solution to California's ongoing water woes — something to consider along with other supply options, including increased wastewater recycling. "The key questions," Cooley said of the desalination plants, "are when do you build them and how large do you build them?"

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As you can see from the above, there is a much easier way to initially get started with the Tsunami. That being to just builds a power generation unit for desalination plants. No permits, knowing flow requirements, desired power output etc.

This will concentrate the creative focus on the task of final developing and perfecting the Tsunami and it’s controls, a formidable task by its self, and then develops the Tidal Generator, using the knowledge and funds produced by the desalination efforts.

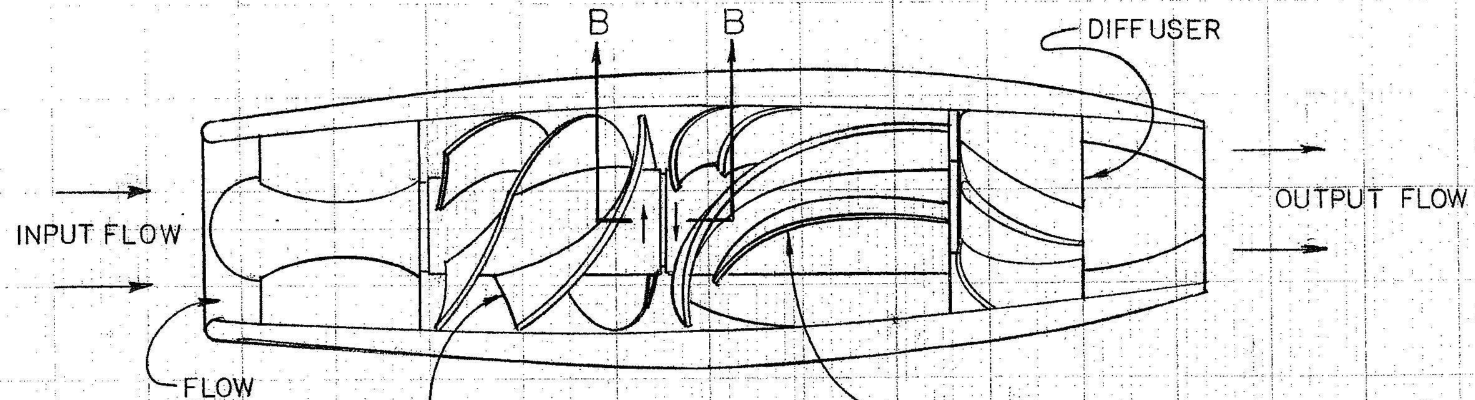


FIG. A

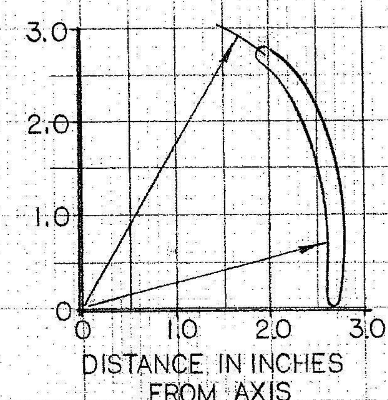
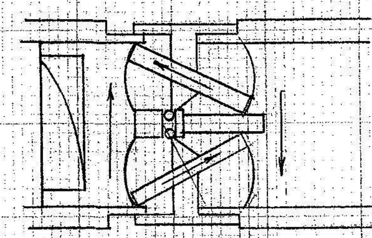


FIG. C



SECTION B-B

FIG. B

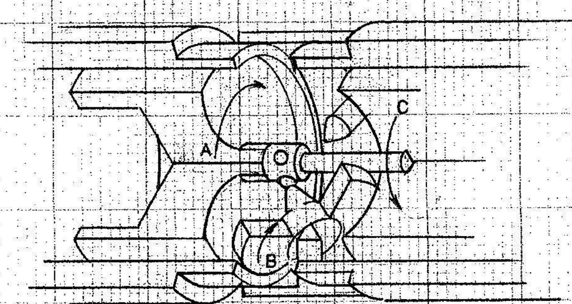


FIG.B - TOROID CUT-AWAY FOR CLARITY

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