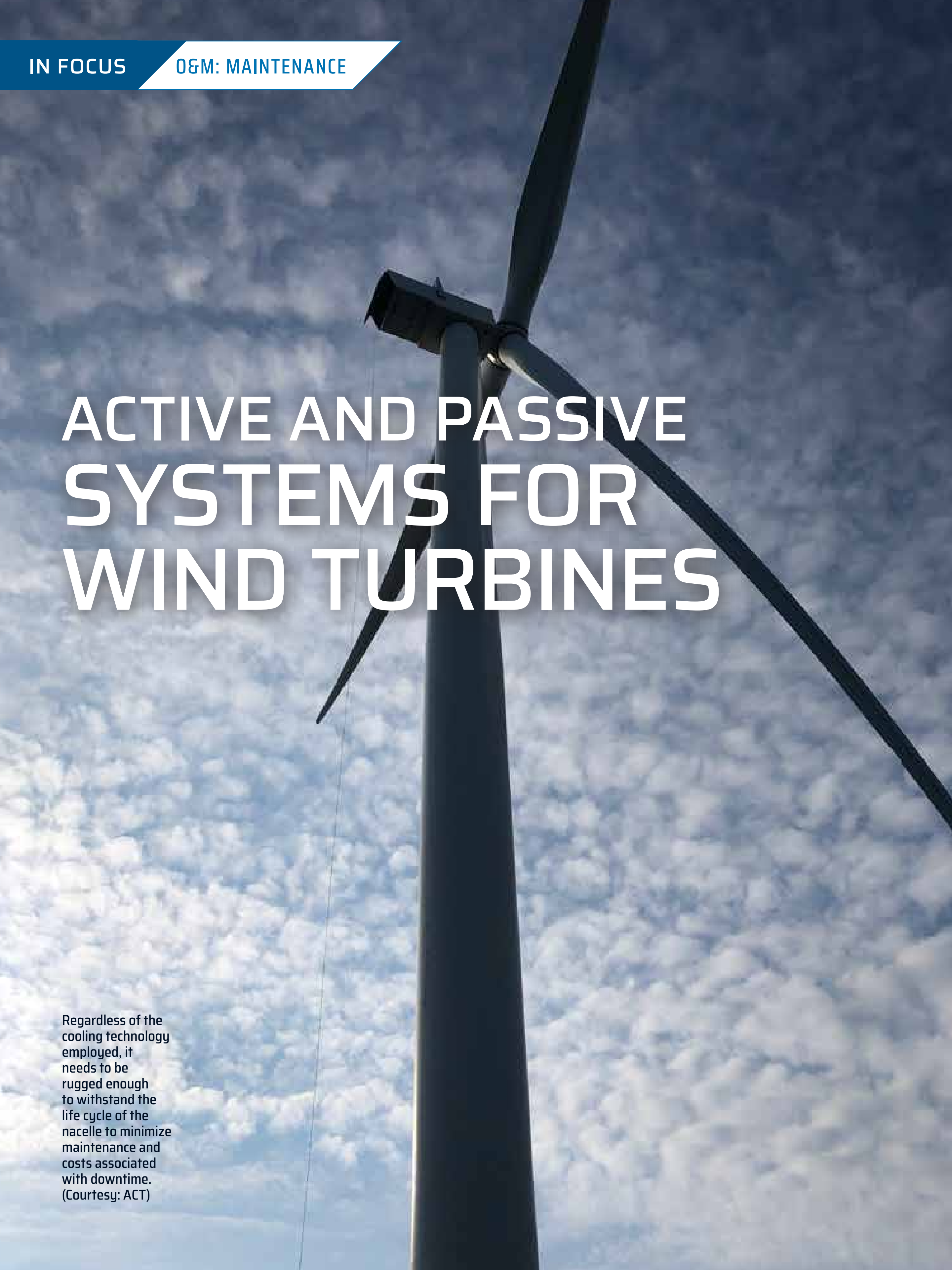
# ACTIVE AND PASSIVE SYSTEMS FOR WIND TURBINES



Regardless of the cooling technology employed, it needs to be rugged enough to withstand the life cycle of the nacelle to minimize maintenance and costs associated with downtime. (Courtesy: ACT)

*In the realm of wind energy, efficient thermal management within wind-turbine components, particularly the nacelle, is essential for optimizing performance and reliability.*

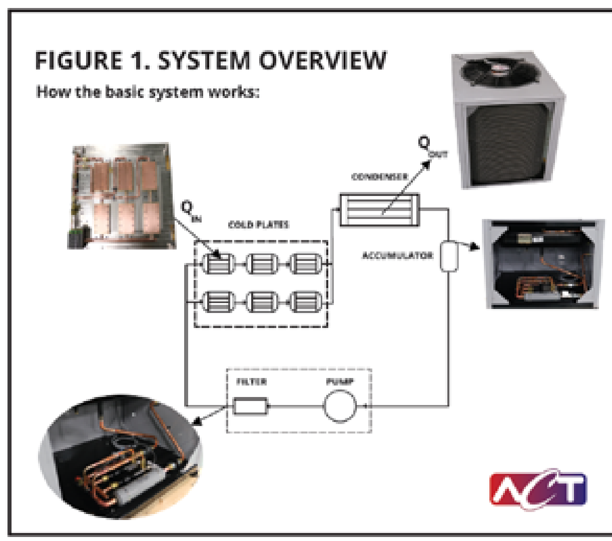
**By HALEY MYER**

Wind energy has emerged as a pivotal player in the global transition toward sustainable energy sources. However, the efficient operation of wind turbines is contingent upon managing heat dissipation within their components, particularly in the nacelle, where critical machinery operates.

Loop thermosyphons offer a reliant passive solution, leveraging the latent heat of a working fluid to enhance the cooling efficiency of wind-turbine components or systems. Loop thermosyphons require no power to operate and have a relatively simple design. However, they are not well suited for applications against gravity or long distances, but this could be mitigated to an extent with a pump-assisted loop thermosyphon. On the other hand, pumped two phase systems offer a unique active solution, increasing the heat removal of a system for the same temperature difference and offering great flexibility in terms of orientation and piping design. However, they do require power to operate and are relatively more complex to design. Active and passive systems provide their own unique sets of advantages to manage heat in the nacelle of the wind turbine and choosing between a system will depend on the heat load, power consumption, sizing, and cost requirements of the system.

Regardless of the cooling technology employed, it needs to be rugged enough to withstand the life cycle of the nacelle to minimize maintenance and costs associated with downtime. A variety of techniques can be used to ensure products are suited for their own unique environment.

Condenser coil on the nacelle of a wind turbine for a loop thermosyphon. (Courtesy: ACT)




Schematic showing ACT hardware for the basic components on a Pumped Two-Phase system. (Courtesy: ACT)

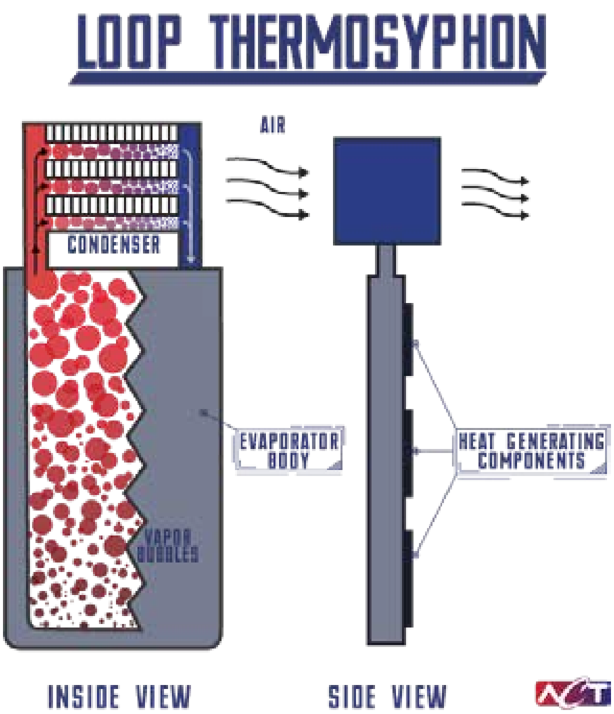
## ACTIVE SYSTEMS FOR WIND TURBINES

In order to cool high-power electronics in wind-turbine applications, an active pumped two-phase system should be considered. In a pumped two-phase system, a non -corrosive, non-conductive coolant evaporates upon contact with hot electronics. This closed-loop system is compact, lightweight, and highly efficient, consisting of a pump, reservoir, cold plate or cooling coils, and a condenser. Unlike traditional water-cooling systems, where the liquid merely heats up, this system turns refrigerant liquid to vapor, significantly enhancing heat removal by using the latent heat in the fluid. Leveraging this two-phase evaporation process, this system can remove two to four times more heat for the same temperature difference compared to single-phase water cooling. This translates to increased power throughput for the same system size, as heat removal capacity dictates the maximum reliable operating temperature.

## BENEFITS OF A PUMPED TWO-PHASE SYSTEM

**1. Increased power density and reliability:** Switching to the two-phase evaporative approach removes safety and maintenance issues linked with water cooling while boosting system-level power densities. This method's isothermal nature also prolongs the lifespan of turbine electrical components by minimizing thermal cycling. Sub-systems such as generators, transformers, and power-conversion electronics can reliably support up to 40 percent more power for the same size/weight, as additional thermal loads are eliminated without raising subsystem temperatures. With more efficient cooling, fewer power modules and supporting infrastructure are needed, reducing both size and weight while cutting overall system costs by using fewer components.

Schematic illustrating how a loop thermosyphon functions. (Courtesy: ACT)




Custom loop thermosyphon hardware. (Courtesy: ACT)

**2. Smaller thermal system in the nacelle:** The pumped two-phase system's compact size and reduced weight compared to other thermal management options creates extra space in the nacelle. Despite using only one-fifth of the flow rate of water, evaporative cooling achieves the same thermal performance, thanks to its higher thermal capacity. This allows for smaller, lighter pumps with lower power consumption, as well as simpler, smaller diameter hoses and manifolds. By integrating pumped evaporative refrigerant units with existing copper coils, power throughput capacity can increase by 30 to 40 percent, instantly reducing size and weight without requiring a system redesign.

**3. Less maintenance in wind applications:** The evaporative precision cooling system requires no regular servicing, a crucial advantage for offshore wind farms facing accessibility challenges. Harsh winter conditions often render wind farms completely inaccessible for days, but a two-phase system minimizes downtime with its virtually maintenance-free features. These features include:

- Hermetically sealed design with pumps offering over twice the reliability of water pumps.
- Leak-proof system: if damage occurs, the non-conductive coolant vaporizes harmlessly.
- Coolant doesn't freeze or require additives; it is non-conductive, non-reactive, and non-corrosive.
- Only includes a dryer filter to remove residual water, eliminating corrosion potential.
- No deionizer needed.
- Equipped with dry break connectors for quick module replacement, reducing downtime during component failure.

## PASSIVE SYSTEMS FOR WIND TURBINES

**How does a Loop thermosyphon work in a wind turbine?**

A loop thermosyphon is a gravity driven, passive, two-phase heat-transfer device that transfers heat from a heat

Custom loop thermosyphon hardware. (Courtesy: ACT)

E-Coated Condenser Coil. (Courtesy: ACT)

source to a heat sink. Its operation is based on the principle of gravity-driven fluid flow within a closed loop containing a working fluid, typically a refrigerant.

The heat-transfer process, as applicable to wind turbines, can be explained in four steps:

**1. Evaporation:** The loop thermosyphon's evaporator section would be within the nacelle, where heat-generating components such as the gearbox, generator, and electronics can be found. Here, heat is absorbed by the working fluid, and the working fluid undergoes a phase change from liquid to vapor, absorbing latent heat in the process. This vaporization causes a decrease in fluid density, promoting upward movement within the evaporator section.

**2. Vapor Flow:** The vaporized working fluid flows upwards through the loop, driven by the density difference between the liquid and vapor phases. This gravity-driven circulation ensures continuous flow from the evaporator to the condenser section.

**3. Condensation:** The vapor flows to the condenser section, typically in a cooler region of the turbine or on top of the nacelle, where it condenses back into liquid form, releasing heat in the process. This condensation releases latent heat, completing the heat-transfer process. The condensed liquid flows back to the evaporator section due to gravity, restarting the cycle.

**4. Continuous Circulation:** This cycle of evaporation, vapor flow, condensation, and liquid return continues as long as there is a temperature difference between the heat source

Heresite™ coated copper tubing and stainless over-braid flex lines. (Courtesy: ACT)

and the heat sink. This continuous circulation of the working fluid facilitates efficient heat transfer without the need for external pumps or mechanical components, making loop thermosyphons a reliable and energy-efficient cooling solution.

## ADVANTAGES OF LOOP THERMOSYPHONS FOR WIND-TURBINE COOLING

**1. Passive operation:** Loop thermosyphons operate passively, requiring no external power source or mechanical components for fluid circulation. This inherent simplicity enhances reliability and reduces maintenance requirements, making them ideal for remote wind-turbine installations. There is no concern of a pump failing, as opposed to other active systems.

**2. Enhanced heat transfer:** The phase change of the working fluid enables more efficient heat transfer compared to traditional liquid cooled loops, allowing loop thermosyphons to effectively dissipate heat from critical components within the wind turbine, thereby preventing overheating and prolonging equipment lifespan.

**3. Maximized turbine performance:** By maintaining optimal operating temperatures within the nacelle, loop thermosyphons contribute to improved thermal management, which is essential for maximizing turbine efficiency and overall energy output.

**4. Environmental sustainability:** The use of loop thermosyphons, a completely passive device, aligns with efforts to promote environmental sustainability in wind-energy production. By minimizing the energy consumption associated with active cooling systems, loop thermosyphons help reduce the carbon footprint of wind-turbine operations.

**5. Cost-effectiveness:** The simplicity of design and passive operation make loop thermosyphons a cost-effective cooling solution for wind turbines, offering long-term economic benefits through reduced energy consumption and maintenance costs.

## RUGGEDIZING PRODUCTS FOR HARSH ENVIRONMENTS

Coastal regions are a strong candidate for wind-turbine farms due to strong offshore winds and favorable topography; however, they come with challenges such as adverse weather and accelerated corrosion rates due to humid, salty air. To ensure products have reliable power — especially those that will be used in remote applications with harsh terrains — it will be necessary to make them as rugged as possible. Outfitting needed products to withstand extreme environments is critical. Heat-exchanger coils may need to be e-coated with a protective film, so they can withstand environments ranging from remote desert terrain to coastal environments to freezing temperatures in areas such as remote Alaska.

In addition, many products made by ACT receive a Heresite™ coating on the copper tubing to withstand highly corrosive environments such as PCM salts and salty environmental air. Fans and blowers may need to be equipped to withstand the harshest rain-, salt-, fog-, moisture-, and dirt-exposure environments. Any sheet metal aluminum may need to be conversion coated and/or powder coated for corrosion protection, as well as being validated for rigorous shock and vibration requirements. Various FEA- and CFD-platform analysis for thermal systems in high-wind and high-G-loading conditions also should be implemented. Quality products should be validated to MIL-STD-810, the military environmental conditions testing standard, with requirements that include blowing sand and dust at high-wind speeds.

The ability to strengthen products for any environment is an ideal skillset to ruggedize future wind-turbine-pumped, two-phase systems for harsh weather environments and corrosion potentials intrinsic in offshore and coastal wind-turbine farms.

In conclusion, active and passive systems each have their own unique benefits to solve the toughest thermal management challenges. In the realm of wind energy, efficient thermal management within wind-turbine components, particularly the nacelle, is essential for optimizing performance and reliability, and a ruggedizing system fit for the needs of the application is paramount to the success of the thermal management design.


### ABOUT THE AUTHOR

Haley Myer is a product development engineer II in ACT's Vapor Refrigeration Group. ACT specializes in engineering and manufacturing system solutions aimed at enhancing the levelized cost of energy (LCOE) through innovative thermal management strategies. With a wealth of expertise in designing, manufacturing, and rigorously testing both active and passive systems — ACT ensures its products are ruggedized to thrive in diverse and extreme environments. From conceptualization to execution, ACT offers a diverse portfolio tailored to address even the most intricate thermal management challenges. For more information, go to www.1-act.com/industries/energy.