Moving more than goalposts

ABB drives open and close the giant panels of a stadium roof – and motor starters move the playing field

Ken Graber

As professional sports venues become bigger and more complex in design and scale, architects and engineers are looking for bold new ideas. Retractable roofs have become a popular feature in such structures because they provide the ability to control the stadium's interior environment more effectively. Only a select number of companies have the knowledge and expertise to mechanize and control these immense structures, which, themselves, become architectural feats.

Uni-Systems, based in Minneapolis, Minnesota, is just such an expert. Whether it's a retractable roof, a retractable pitcher's mound, movable walls or seating, Uni-Systems has established itself as the industry's premier provider. The company's impressive resume includes work on Minute Maid Park and Reliant Stadium, Houston, Texas; Miller Park, Milwaukee, Wisconsin; RFK Stadium, Washington, D.C.; and most recently, the Arizona Cardinals' stadium, Glendale, Arizona.

With its curved roof track, the Arizona Cardinals' project presented fresh challenges in designing the retractable roof mechanism. Uni-Systems partnered with ABB and selected the ABB ACS800 drive to provide optimum control of the roof's torque-distribution system.

An architectural oasis in the desert

When, several years ago, the National Football League's Arizona Cardinals decided to construct a new arena, the desert climate was a major consideration in the design plan. The heat can take its toll on fans and players alike, and can be detrimental to the playing surface – especially if it is natural grass. On the other hand, in cooler months, the world-famous climate is perfect for hosting outdoor activities.

The exterior design of the stadium resembles the basic form of the barrel cactus and was created by renowned architect Peter Eisenman, together with the sports architecture company, HOK Sport. The retractable roof can be closed to permit the facility to be air conditioned in the hot months, and then opened in the cooler months 1. The roof's panels consist of a PTFE (polytetrafluoroethylene) coated woven fiberglass fabric, and are much lighter than a traditional, clad roof.

A moving playing surface

The stadium design includes not only a retractable roof, but also a retractable playing surface 2.

The innovative roll-out field will save an estimated $50 million in operating costs, as it is more economical to move the field outside than to retract the entire roof sufficiently to allow the necessary sunshine to reach the grass. The retractable, natural-grass playing surface is contained in a 16.9 million pound (7.7 million kg) tray that is 234 ft wide by 400 ft long (71 m by 122 m) – the first of its kind in North America. ABB motor starters activate the motors that retract the field. All in all, the design of the stadium is so unique that it has featured in a multiple-part series on "The Discovery Channel."

Direct torque control

This roof was different from any that Uni-Systems had previously constructed. According to Lennart Nielsen, Danish master electrician and senior electrical designer with Uni-Systems, one of the most important decisions was selecting motor drives to control the roof's movement.

"An important factor in choosing the ABB drives was the inherent risks associated with running a roof on a sloped track," says Nielsen 3. "This caused us to look for a variable-frequency drive (VFD) that would allow us to test the drive torque before each roof motion, to ensure that each drive was operational and capable of a 100 percent torque output. The ACS800 was capable of this, so before each motion, the programmable logic controller (PLC) checks the torque output from the VFDs at 0 Hz, before committing to opening the motor brakes." Nielsen also says the ABB drives could be installed and operated without the need for closed-loop encoders – a cost-effective option that helped the company meet budget requirements.

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On the roofs that Uni-Systems had previously designed, if the motors didn't start up for some reason when the brakes were released, the roof would simply remain in place. At the Cardinals' new stadium – with its sloped roof track – such a situation could see the roof sections fall into the parking lot.

1 The retractable roof on the new Arizona Cardinals' stadium in Glendale, Arizona is powered by ABB ACS800 Drives.

2 The entire playing surface can be rolled out of the stadium.

"The ABB set-up, with its direct torque control, can measure the feedback from the motor much more accurately than a standard drive," explains Nielsen, "and in their control/output algorithms, they can measure the characteristics coming back from a motor at 0 Hz (meaning that they start the energy field without rotating the motor), and that's a big reason why we chose them."

"We wanted to have this capability all the way down to 0 Hz, and none of the manufacturers – except ABB – could guarantee that," Nielsen continues.

ABB drives critical to roof functionality

The retractable roof consists of two moveable panels suspended between two parallel tracks along the east and west sides of the structure 4. The tracks are curved to follow the roof's slightly domed profile, which slopes down from its apex at the 50-yard line towards the north and south ends of the building. Each roof panel rests on eight two-wheeled carriers: four along the west and four along the east side of the roof panel; each set of four carriers forms one quadrant of the entire retractable roof system.

Conventional techniques – such as the powered traction wheels that Uni-Systems used on previous stadium projects – were not an option for the Arizona stadium's sloped roof. Instead, Uni-Systems designed a system in which each roof panel is tethered by four 1.5 inch-diameter (3.8 cm) steel cables on each side.

There are two cables running on each side of the roof rail, and each is wound on its own 48-inch-diameter (122 cm) cable drum. The cable drums are arranged with one on each side of the two upper carriers for each roof panel quadrant, and the two lower carriers in each quadrant are not powered. Each cable drum is equipped with a bull-gear along the outer rim, driven by four geared, 7.5 HP (5.6 kW), 480 V AC motors with spring-set brakes 5.

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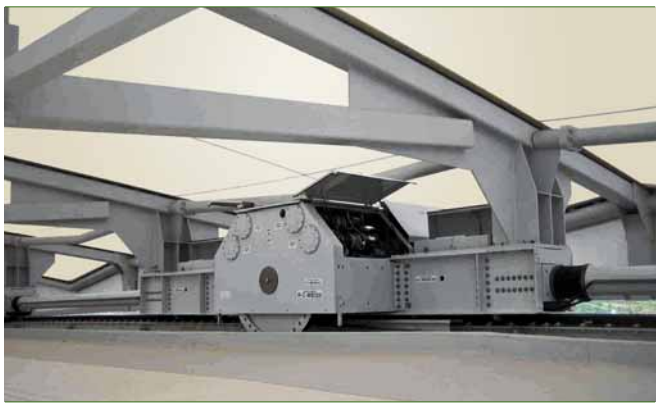
The four motors per drum are controlled by two 20 HP (15 kW) ACS800 variable-frequency drives (VFDs), meaning that each roof quadrant is powered by 16 motors that are controlled by eight VFDs. Accurate control of the VFDs was essential to distribute the load evenly to the roof cables. "It was deemed inadequate to let the roof PLC act as referee for each individual drive via the ProfiBus that was to handle the regular data communications between the PLC, VFDs, and remote I/O," says Nielsen. "Instead, we use a parallel, fiber-optic communications network between each group of eight VFDs, where one VFD was designated as master and the other seven as followers."

Once the roof is moving, it is extremely important to keep a very tight torque-and-speed envelope around each follower drive in relation to each roof quadrant's master VFD," Nielsen continues. "The ultra-fast switching Direct Torque Control system of the ACS800 provides the means for doing this via the fast intra-VFD fiber-optic network."

The PLC issues a speed (frequency) command to each of the two master VFDs (one per side) and the seven follower drives then match the torque output of the master drive. Each roof panel's PLC handles the position alignment between the two quadrants of each roof panel, which receives position feedback from an absolute encoder in each quadrant and from incremental encoders on each cable drum. If a roof side gets more than two inches ahead of the other – the rails are 257 feet (78 m) apart – the PLC will signal the master of the leading side to slow down until the two sides are again in alignment.

Since the roof rails are curved, the actual cable load increases as the roof panel moves towards the fully open position and the steeper sections of rail. For optimum motor torque, the VFDs output 60 Hz at the lower half of the rails, and to decrease operating times, 85 Hz on the upper half. Motors

3 Because the roof panels follow a sloped track, Uni-Systems wanted a drive that would check its torque before each roof motion to ensure the drive was fully operational. ABB was the only manufacturer that could measure characteristics from the motor at 0 Hz.



4 The retractable roof consists of two moveable panels suspended between two parallel tracks.

operate in both motoring and generating modes – generating when the panels are lowered, and motoring to lift and close the panels.

The ABB drives require no maintenance. They are mounted in air-conditioned enclosures that are on the carriers.

Cable oscillations

During initial testing at the Cardinals' stadium, Uni-Systems found that natural frequencies in the drive cables caused some oscillation or whipping in the cables as the roof was opened. "And the faster we ran, the more pronounced it was," says Nielsen. "We saw that the drives actually made it worse. As each cable oscillated, the anchor points of the cables would see a varying torque. The master drive would then react to those changes by increasing or decreasing its torque output. And its torque profile would then be transmitted to the other drives that reacted to it – causing the whole cable system to start into harder and harder oscillations."

5 Each cable drum has a bull-gear along the outer rim, driven by four geared, 7.5 HP, 480 VAC brake motors and the four motors per drum are controlled by two, 20 HP ACS800 drives.

This was an unforeseen challenge: ABB engineers visited the site to help Uni-Systems tune the drives to this situation and deliver optimum control while eliminating the bounce in the cable as the roof opened. Nielsen says, "Our natural reaction would have been to just open up the tolerances more to allow a larger window around the optimal speed and torque to permit a little bounce without the drives reacting to it. But ABB went the opposite way and actually made that window extremely small so as not to allow it to react harshly enough to cause the oscillation."

"We simply needed to utilize a standard software feature in the ACS800 which allows for loadshare (torque) followers to have an over-riding speed window about the master drive's coordinated speed reference," Boren said.

"Because of the uneven cable stretch – which can be viewed as slip between the driven cable drums – it's tough to make the drums share the load evenly. But by activating the ACS800's speed window capability in the torque follower drives, and limiting the window (slip) to only 2 rpm on each motor, the cable drums have no choice but to evenly share the load of the immense roof."

Projects underway

With the Arizona Cardinals' stadium nearing completion, Uni-Systems and ABB will soon turn their collective attention to several more new NFL stadium projects. Already in progress in Indianapolis, the Colts are replacing the RCA Dome with a new, state-of-the-art retractable roof stadium. "The system required for that roof is much more complex," says Nielsen. "Instead of a nearly one-to-one, width-to-length ratio, the Colts' panels are around five-to-one. This has resulted in a five-rail design, rather than a two-rail as in the Cardinals' stadium, and twice as many cables and drives. Also in progress is a design for the new Dallas Cowboys' Stadium. Both of these stadiums will use the newer ACS800-U11, or regenerative drive, which was not available when the Cardinals stadium was designed." The Cardinals' Stadium design uses stand-alone regenerative drives working with the ACS800 VFDs.

As both Uni-Systems and ABB gain more experience in this niche business, even bolder designs are to be expected in the near future.

Factbox 1 Retractable roof quick facts

- Two retractable roof panels at 1,100,000 lb each (550 tons)
- Each roof panel's dimensions: 185 ft long by 285 ft wide by16 ft deep (56 × 86 × 4.9 m)
- 8 cables of 1.5 in diameter (3.8 cm) connect each retractable roof panel to the stadium structure at the 50-yard line (over half a mile of cable used)
- 32 motors of 7.5 HP (5.6 kW) power each roof panel adding up to 480 HP total for stadium (358 kW)
- 16 crane wheels of 36 in diameter (97 cm) support each retractable roof panel
- 595,000 lb (270 t) of mechanization equipment used to make the roof move
- 257.5 ft (78.5 m) span of retractable roof over stadium bowl
- Two rail lines with 175 lb/yd crane rail (over a quarter mile of rail used)
- Maximum travel speed: 25 ft/min or 0.25 mph (0.4 km/h)
- Total travel time: 11.5 min. (10 min. run time, plus 1.5 min. of slow speed for final positioning)

Factbox 2 ABB and drives

ABB is the world's largest manufacturer of electric motors and drives. The company supplies a complete line of energy-efficient electric drives, motors and engineered drive systems to a wide range of industrial and commercial customers. Products manufactured include AC and DC variable-speed drives for electric motors from 1/8th through 135,000 HP, and application-specific drive system solutions to meet diverse customer needs (http://www.abb.us/drives).

Ken Graber
ABB Automation Technologies
New Berlin, WI, USA
ken.j.graber@us.abb.com