NASA's Solar Dynamics Observatory captured this image of a solar flare in October 2021. The image shows extreme ultraviolet light that highlights the extremely hot material in flares – colorized here in teal. Credit: NASA/SDO

Protecting the grid from solar storms

More than three years into what scientists call "Solar Cycle 25," WAPA has taken an innovative step towards better protecting the electrical transmission system from the risks of space weather caused by our favorite star: the sun.

In November 2022, employees energized WAPA's first-ever neutral blocking device at White Substation in South Dakota. Upper Great Plains Maintenance experts installed the NBD in the neutral of a large power transformer to block geomagnetically induced currents, or GICs, during solar storms.

"If these GICs are significant, they can cause physical damage to power transformers and stress the transmission system's ability to compensate for abnormal voltage dips, potentially pushing the electrical system to the point of collapse," said Vice President of Engineering and Design **Dan Hamai**.

This is the first commercially developed NBD installed in the U.S., and only the second device of its type to become operational. The NBD project, funded by the Department of Energy's Office of Cybersecurity, Energy Security and Emergency Response, serves as a national pilot program to install, test and evaluate technology designed to mitigate the effects of GICs in transformers.

Geomagnetic disturbances caused by space weather events such as massive solar storms can distort Earth's protective magnetic field. When wobbles in Earth's magnetic field induce electrical currents, they may travel through electric transmission lines and into grounded transmission equipment.

GICs resulting from severe geomagnetic disturbances can saturate transformers and cause negative impacts including reactive power absorption and voltage drops, electrical harmonics injected into the power system and overheated transformers.

"By effectively blocking GICs that flow through the transformer, these novel NBDs installed at strategic locations in the power system may reduce and possibly eliminate these negative effects," Hamai said.

The NBD uses three paths to ensure the transformer neutral maintains its ground connection, providing an effectively grounded system in all

operating modes. These paths include a solidly grounded metallic path, a GIC-blocking path using a capacitor bank and an overvoltage protective path through a spark gap. When the GICs exceed a threshold setting, the NBD automatically opens the solidly grounded path, which directs all neutral current through a low impedance capacitor bank, effectively stopping the rogue current from sneaking onto the transmission system.

GICs are quasi-direct current, meaning they oscillate at frequencies so low that they act like direct current. Significant and sustained direct currents are rare on WAPA's alternating current transmission system and can cause detrimental effects when they flow. This explains why engineers use a capacitor in the blocking path. When faced with a GIC, the capacitor functions like an open circuit, blocking the GIC's flow.

"Ultimately, the benefit of this NBD design is to mitigate GMD effects on the transformer while maintaining a solid metallic grounded neutral under normal operating conditions, which is critical for equipment insulation and protective relay operation," said Transmission System Planning Manager **Chris Colson**.

Following a GIC mitigation pilot program report from the Electric Power Research Institute, WAPA experts performed two system studies to identify and analyze preferred locations for the NBD within the organization's transmission system. In the first study, UGP transmission planners performed a specialized GIC flow study to determine how solar storms of varying orientations and magnitude may cause GICs to develop on the transmission system.

They simulated placing NBDs at various crucial nodes, including large power transformers at substations positioned to serve numerous customers and sites.

The experts then analyzed the effectiveness of a GIC-blocking device in the field. They determined the transformer "KU1A" at White Substation would make the best Upper Great Plains candidate for NBD installation.

"White KU1A met our criteria as a substation transformer that connects to three or more adjacent substations

An Upper Great Plains Maintenance crew quickly installed WAPA's new neutral blocking device at the White Substation in September 2022.

with large bulk electric system transformers," said Colson.

"In other words, blocking GICs at this transformer allows any significant GICs developed on the long 345-kilovolt transmission lines terminating at White Substation to become somewhat reduced, but more importantly safely redistributed, finding paths to ground at adjacent substations," he said.

For the second study, an architectural engineering firm completed the "White Substation NBD Impact Study," which included transient switching analysis, harmonics analysis and insulation assessment to evaluate the potential impact of the NBD.

If any of WAPA's technical studies showed potential damage to the transformer or negative impacts to system reliability, WAPA would not move forward to purchase and install these GIC mitigation devices.

"We were pleased to find out that no negative impacts were identified, so WAPA moved into the design and NBD specification phase," Hamai said.

After finalizing the designs, WAPA procured the NBD from Emprimus LLC, which delivered it to White Substation in September 2022. A South Dakota-based Maintenance crew then installed the NBD controls in an existing control panel.

Due to the uniqueness of the NBD to the transmission system, Emprimus provided operation and maintenance training to grid operators and Maintenance staff. Commissioning took place over the next two months with successful energization in November.

"I often bemoan the sun's irate 'personality,' and maybe it was eager to put the White NBD to the test. In late February 2023, a moderate, double-coronal mass ejection that accompanied solar flares erupted from the sun, pointed at the Earth's orbital position," said Colson.

Just after midnight on Feb. 27, the solar storm rocked the Earth's magnetic field, giving rise to a strong GMD event. The National Oceanic and Atmospheric Administration's Space Weather Prediction Center, which uses a five-level scale similar to the hurricane wind-scale system, categorized the storm as a 'G3' GMD event.

"No worries, the White NBD was ready! On four separate occasions, the White NBD operated as expected, sensing the rise in GIC flow and automatically initiating its blocking during the space weather event that lasted about twelve hours," said Colson, who admits to eagerly awaiting the next coronal mass ejection event.

"With the White NBD in service and plans to extend the WAPA GIC monitoring network to improve situational awareness during GMD events, WAPA is well-positioned for whatever the sun cooks up," he added. □