A Report From
ETAP Nuclear Utility Users Group

Open-Phase Analysis for Nuclear Power Plants

Collaborative effort results in industry's first commercially available software validated to analyze the effects of open-phase faults

Nuclear power plants around the world have made headlines in recent years because of controlled reactor shut downs precipitated by partial losses of power known as "open-phase faults." A reliable source of offsite electric power is critical to the safe shutdown of a nuclear power reactor. Offsite power is normally supplied from the local transmission system via conductors from each of the three phases. An open-phase fault occurs if one or two of the three conductors fails open (conductor disconnects) exposing the in-plant safety systems to a potentially undesirable situation that may lead to failure.

Following an open-phase fault event at Byron Nuclear Power Station near Rockford, Ill. in 2012, the Institute of Nuclear Power Operations (INPO) began to raise awareness of this potential nuclear plant design vulnerability in the U.S. By 2013, four open-phase fault events had occurred at nuclear power plants in the U.S., Canada, and Sweden, which prompted the World Association of Nuclear Operators (WANO) to raise awareness outside the U.S. The challenge open-phase faults create for a nuclear power plant, according to reports published by U.S. Nuclear Regulatory Commission (NRC), is that the loss of a phase on the offsite power source can potentially damage both redundant trains of the emergency core cooling system, but may not be detectable by existing protection systems. Thus, there could be an open-phase fault that goes undetected by nuclear plant operators. Due to the seriousness of this issue, the Nuclear Energy Institute (NEI), a policy organization of the commercial nuclear industry, got involved by forming a steering committee and working group of industry experts focused on organizing an industry-wide initiative to resolve it.

The consequences of an open-phase fault can be entirely different at each nuclear power plant. Research performed by The Electric Power Research Institute (EPRI) has shown that the consequences largely depend on the specific design of the offsite power transformer feeding the plant's nuclear safety systems. This means in-depth power system analysis is required to determine the exact consequences for each plant. Thus, governmental, engineering, and industry organizations have been collaboratively focused on developing analytical modeling techniques to study the effects of open-phase faults, with an overall goal of developing any necessary counter-measures to mitigate a design vulnerability.

ETAP is the most commonly used software in U.S. nuclear power plants. In fact, 97% of these plants already use ETAP to analyze their auxiliary power systems, which means that detailed models of these plant's electrical systems already exist. However, at the time of the initial open-phase fault events at Byron, ETAP software did not include the capability to analyze an open-phase fault. While there were other software tools available that could be used to simulate an open-phase fault, these were not well-suited for performing a comprehensive analysis of the effects the fault may have on each of the numerous electrical loads throughout various safety systems. Early attempts to use some of these software tools emphasized that their use would become cost-prohibitive, especially when iterative analyses were needed. This was not a viable solution for the nuclear industry because ultimately such high costs for performing engineering analysis would have to be passed along to electric utility customers.

ETAP Nuclear Utility Users Group Tackles the Problem

Because ETAP software is the de facto standard for design and analysis of the power systems at U.S. nuclear power plants, many power system analysis experts throughout the U.S. nuclear industry are members of the ETAP Nuclear Utility Users Group (ETAP NUUG). They were determined to find a way to use the software they use for everyday work to study this new issue.

Under the leadership of ETAP NUUG Technical Chair Mark Bowman, the ETAP NUUG began working with the ETAP development group shortly after the Byron open-phase events in 2012 to enhance the software's ability to accurately simulate open-phase faults. They quickly focused on the ETAP Unbalanced Load Flow module. The ETAP NUUG worked side-by-side with the ETAP software development team to document their requirements – while concurrently reviewing changes to the software as it was being developed. In March 2013, Bowman formed the ETAP NUUG Open-Phase Task Force, a team of power system analysis experts which included NUUG Executive Chair Neal Simmons, Associate Chair Paul Colaianni, as well as others from Duke Energy, Enercon Services, Inc., Exelon Corp., MPR Associates, Inc., Sargent & Lundy, LLC, Southern Nuclear, and Tennessee Valley Authority (TVA). Their mission: assess the ability of the newly-designed ETAP Unbalanced Load Flow module to perform a detailed quantitative analysis of an open-phase fault for a typical nuclear power plant.

Over the course of many months, in which thousands of man-hours were invested by both ETAP and industry experts from the ETAP NUUG, the ETAP Unbalanced Load Flow module was successfully enhanced to be able to model and analyze the effects of both single and double open-phase faults. And the ETAP NUUG Task Force completed the mission by demonstrating that the new capability could be used to perform open-phase fault studies on several types of existing nuclear plant power system designs, as well as to simulate the open-phase fault that occurred at the Byron Nuclear Power Station – with very accurate correlation to the actual event. In the end, this collaborative effort has resulted in the industry's first commercially available software that is verified and validated to analyze the effects of an open-phase fault.

ETAP Nuclear Utility Users Group

The ETAP enhancements have been reviewed and applauded by ETAP users at both the 2013 and 2014 ETAP NUUG Conference and Symposium. The work of the ETAP NUUG on the enhancement of ETAP was recognized by the NRC at a Washington, D.C. public meeting in June 2013. WANO also recognized the importance of this effort by requesting a presentation at the January 2014 Open Phase Workshop in Paris. As a bonus, the new ETAP capabilities directly align with guidance recently provided by the NRC in a (draft) technical position document on open-phase conditions.

Here is what others say about this achievement:

> "I was particularly impressed when ETAP and their nuclear users group quickly responded to a request by the nuclear industry to address the modeling of a new vulnerability. The dedication of highly skilled programmers to work closely with industry power system experts resulted in a product that will be useful in developing open-phase indication circuitry to maintain the health and safety of the public." Gordon Clefton - Senior Project Manager, Nuclear Energy Institute
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> "Accurately identifying the impact of open-phase conditions on a plant distribution system was a significant industry challenge. The prompt, diligent response that the ETAP staff provided the industry - working through their nuclear users group to update and validate the ETAP models - helped to develop the confidence that the analysis results were technically sound. The ETAP staff, working with the users group, is a great example of proactive engagement and response needed to solve a complex issue." Shawn Simon – Principal Evaluator, INPO
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> "The efforts of this user's group have been instrumental in development of our design concept for open-phase fault protection" - Rob Whalen - VP Nuclear Engineering, TVA

Recounting the presentation by the ETAP NUUG in Washington D.C., Bowman said, "One purpose of this public meeting was for NEI to demonstrate to NRC that the nuclear power industry was being proactive, timely, and responsive to recent open-phase events. The efforts of ETAP and the ETAP NUUG, were a good example of this and were well-received by NRC". Bowman concluded by praising Simmons and Colaianni of Duke Energy, as well as Tamatha Womack of TVA; Colaianni is Chair of the NEI Open Phase Steering Committee and was instrumental in working with both NEI and NRC. Simmons and Womack were instrumental in building and testing representative nuclear power plant models to test the newly designed software.

Members of the ETAP development team were gratified their contributions provided such significant value; specifically to electrical analysis engineers and generally to the nuclear power industry. "ETAP has enjoyed a very special partnership with the nuclear power industry since the Company's inception nearly 30 years ago," said Farrokh Shokooh, President and CEO of ETAP. "Though it represents a relatively small part of our software revenue, the nuclear industry is a large part of our company culture because of its unrelenting focus on safety and

quality. Meeting the quality standards set by our nuclear customers has benefitted our commercial, government, and military users as well." He added that the full open-phase fault analysis capabilities are commercially available in ETAP's most recent software release.

This collaborative effort between expert power system analysis engineers from the U.S. nuclear utility industry and expert software designers at ETAP resulted not only in advancing the capabilities of the software to analyze a new type of fault, but has helped to further improve the safety of nuclear power plants worldwide.

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ETAP Nuclear Utility Users Group Officers - 2012-2014

Executive Chair: **Neal Simmons**
Sr. Analysis Engineer, Nuclear Generation, Duke Energy

Technical Chair: **Mark Bowman**
Sr. Program Manager, Power System Analysis, Tennessee Valley Authority

Associate Chair: **Paul Colaianni**
Manager, Fleet Electrical Analysis, Nuclear Generation, Duke Energy

About ETAP NUUG

The ETAP Nuclear Utility Users Group (NUUG) is a technical organization dedicated to issues of interest to Nuclear Utility professionals involved in the modeling and analysis of power systems in their facilities. The Annual ETAP Nuclear Utility Users Group (NUUG) Conference & Symposium offers a technical forum on the modeling and analysis of power systems along with recent issues that are of specific interest to Nuclear Utility professionals.

The ETAP NUUG Conference & Symposium provides a unique opportunity to:

- Share techniques and philosophies used in analyzing nuclear power plant electrical power systems
- Share operating experience related to ETAP-based power system analysis in nuclear power plants
- Address improvement of the ETAP software as a group
- Encourage the exchange of member experiences and ideas

The 14th Annual ETAP NUUG Conferences was held in June 2014 at ETAP World Headquarters in Irvine, CA.