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Protection Scheme of Open Phase Condition for APR1400 NRC DC

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1. Introduction

Based on recent operating experience at a nuclear power plant (NPP), the loss of phase on the high voltage side of standby and auxiliary transformers was not detected. The plant existing under-voltage protection scheme on the 4 kV safety-related bus sections did not detect the loss of phase and did not initiate an automatic protective actions to separate the bus sections from offsite power. The loss of a single phase in the power supply caused phase current to rise in running motors. Many motors at both the medium and low voltage levels tripped on thermal overload, phase over-current, or dropped-out contactors. In some cases, the open-phase condition existed undetected for an extended period and in other case, was not properly responded to. Accordingly, the Nuclear Regulatory Commission (NRC) requested all license holders to take corrective actions to address the open-phase condition.

It was also requested that all holders or applicant for a standard design certification (DC) include a description of a protection system to detect and separate the open circuit into the design control document (DCD).

This paper, a protection system of open phase condition for APR1400 NRC DC is discussed.

2. NRC RAI for Open Phase Condition

In order to verify applicant of APR1400 NRC DC has addressed the design vulnerability identified at Byron in accordance with the requirements specified in General Design Criterion (GDC) 17, “Electric Power Systems,” in Appendix A, “General Design Criteria for Nuclear Power Plants,” of 10 CFR 50, and the design criteria for protection systems under 10 CFR 50.55a(h)(3), the APR1400 Design Control Documents (DCD) should contain a description of how the design conforms the above regulations in regards to the design vulnerability described in BL 2012-01.

The description in the DCD should have sufficient details that the COL applicant can implement the design to detect, alarm and mitigate open phase conditions in accordance with 10 CFR Part 52.47(a)(3)(i) and 52.47(a)(3)(ii).

Additionally, the staff position on this issue is provided in Branch Technical Position BTP 8-9

The cause of the event was the loss of phase C of Byron offsite power as shown in Fig. 1.

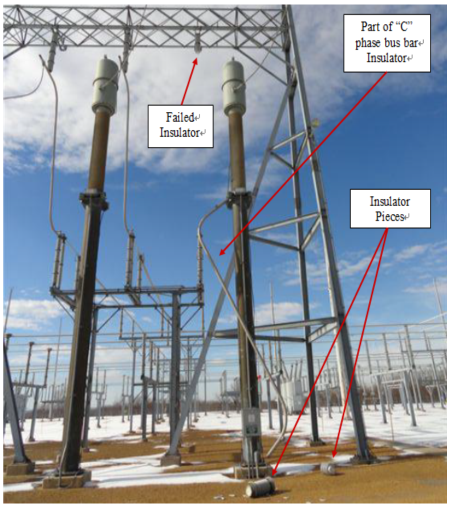

Fig. 1. Loss of Phase Event at Byron Station

3. Protection System of OPC for APR1400

KHNP has performed a design vulnerability study of the APR1400 electric power system for various open phase condition (OPC) scenarios, which are identified in NRC Bulletin 2012-01 and Branch Technical Position (BTP) 8-9. The study evaluates the impacts of an open phase fault with and without high-impedance ground fault conditions on the APR1400 design.

KHNP has also completed a review of the applicable industry OPC solutions based on several examples used in U.S. NPPs to identify the optimal solution for the APR1400. Among the reviewed designs, three different types of open phase detection (OPD) solutions were found to be applicable to the APR1400 electric power system.

For the NRC RAI, KHNP provides a comprehensive approach to resolving the OPC issue identified in NRC Bulletin 2012-01 and BTP 8-9.

3.1 Protection Systems used in NPP fleets in the U.S.

Three OPD systems currently being implemented in NPP fleets in the U.S. are considered to be applicable to the APR1400 electric power system. The general systems of the three industry solution for OPC are as follows.

- PSSTech Open Phase Detection System
- GEALSTEM Open Phase Detection System
- PCS2000 Open Phase Detection System

Each of the OPD systems listed above applies different technologies and algorithms for the detection of an OPC. However, all of the potential solutions have sufficient capability to detect OPCs with the following characteristics at a minimum.

- The OPD system is capable of detecting open phase fault with and without high-impedance ground fault over the full range of transformer loading from no load to full load;

- Each OPD system consists of redundant detection subsystems with voting logic (e.g., 2-out-of-2 or 2-out-of-3) such that any failure in any one of the constituent systems will not cause a spurious trip of the sound offsite power supply;

- The OPD system provides continuous monitoring and self-diagnostics to a remote end (e.g., MCR);

- The OPD system is a non-Class 1E system similar to other offsite power protective devices. Electrical interfaces of the OPD system with the Class 1E protection and control circuits should consider separation requirements in accordance with RG 1.75 and IEEE Std. 384.

3.2 OPC Scheme for APR1400 NRC DC

KHNP's design vulnerability study for the OPC scenarios identified that only the relay protection on the low side of the grid interconnection transformer (i.e., MT and SATs) could allow an open phase condition on the primary side of a transformer to go unnoticed for some period particularly at lower or no load conditions. Voltages and currents on the secondary side are greatly dependent on the winding configuration and also on the transformer's core construction as described in the EPRI Interim Report (Rev. 0), "Interim Report: EPRI Open-Phase Detection Method."

In some cases, the OPCs will cause a further degraded condition such as a large motor trip due to excessive negative sequence current; unless the conditions are properly detected, alarmed, and mitigated against.

In order to ensure that an OPC is properly detected and alarmed in the main control room (MCR) and the degraded power source is automatically transferred to the reliable standby power source, an additional detection and protection system for OPC (namely, OPD system) is being included on the primary-side of power transformers (MT and SATs), in addition to the protective relays which have already been incorporated into the APR1400 design.

Once an OPC is detected by the OPD system, the OPD system sends an alarm signal to the MCR, and trip signals to the Class 1E and non-Class 1E medium voltage (MV) switchgear buses after an appropriate time delay. If an OPC occurs at the primary side of the MT under loading condition, the Class 1E and non-Class 1E MV switchgear buses will be automatically transferred from the UATs to the SATs.

KHNP considers that selection of a specific type of OPD system is within the scope of COL applicant rather than definitively selecting one solution out of the three technically acceptable solutions listed above. It is also possible that an enhanced system design could be available to the COL applicant at the time of the detailed plant design and construction that would be better suited.

4. Conclusion

As a result of the study, KHNP has determined that a dedicated OPD system is being included on the primary side of power transformers, in addition to the conventional protective relays in the APR1400. The minimum required design features of the OPD systems are detection of OPC over the full range of transformer loading, redundant detection subsystems with voting logic to minimize operation failure or unintended operation of the detection and protection, continuous monitoring and self-diagnostics to main control room. Basically, the OPD system is Non-Class 1E, so it should meet separation requirements, as per IEEE 384 for the interface with Class 1E system.

REFERENCES

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