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The NPP Safety Assessment With Consideration Of Smart Substation Reliability

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The Smart Grid (SG) is a movement to bring the electrical power grid up to date so it can assure cutting carbon emissions to near zero in the coming decades. The SG is an upgrade to the current electrical power system, so it has all the functionality of the current power system plus several new functionalities such as: self- healing, motivating and including the consumer, attack resistance, power quality increase, etc.

During COP 28 held in Dubai in December 2023, 22 countries pledged to triple nuclear capacity in a push to cut fossil fuels. The world wants more nuclear energy as a means to fight climate change and supply an ever-growing demand for electricity. NPP is part of sustainable energy so this is also the future part of SG. Digital substation is one of the important assets of the SG, which provides reception, conversion and distribution of electrical energy. In fact, it is the interface between the power plant and the electrical system located in close proximity to the plant.

The SG safety means the achievement of power plans' (including NPP) proper operating conditions, prevention of accidents, resulting in the protection of the public and environment from undue radiation hazards.

The SG reliability is the complex property that determines the ability to perform power supply to consumers by performing functions in the production, transmission and distribution of electrical energy under a single technological interaction between generating installations, electrical networks and electrical installations of consumers at any given time, the demand for power and electricity (adequacy, balance component of system reliability) to withstand perturbations caused by failures from the grid elements (safety, system reliability, operational component).

The SG power plants' operational experience proves Common Cause Failures (CCFs) are a subset of multiple failures and main contributors to the accident risk's increase. The failure of multiple components due to a common cause represents one of the most important issues in the evaluation of the I&C reliability or unavailability.

Any SG can be represented as a graph, where the nodes are systems and the edges describe the existing interaction between them. The idea of the nature of interdependencies, cause-effect relationship between nodes lies in fact that systems are not static. A classical BBN is a pair

$$N = \{(V, E), P\}, \quad (1)$$

where V and E are the nodes and the edges of a Directed Acyclic Graph (DAG), respectively, and P is a probability distribution over V.

To assess the impact of the reliability of a digital substation on NPP safety, it is proposed to use the method based on the combined use of BBN and the failure tree analysis method (FTA).

The proposed method involves the following stages:

- definition and structuring of all substation assets;
- risk analysis of substation assets, considering the severity of failures for the substation;
- substation risk asset ranking, taking into account the impact on performance of the digital substation. At this stage, the most critical assets are identified, the failures of which lead to a loss of readiness of the digital substation;
- the construction of BBN, including the node(s), taking into account the digital substation reliability in the form of availability factor, namely, the probability of finding the substation in working condition.

It should also be noted that when BBN and FTA are used together, two cases may arise:

- for the safety assessment, a combination of linguistic BBN and classical (probabilistic) FTA is used. In the linguistic BBN, all network parameters, including conditional probabilities, are represented as linguistic values (LV);
- for the safety assessment, a combination of probabilistic BBN and FTA is used, in which the probabilities of basic events can be partially or completely represented as LV. Fuzzy FTA extension is used in case of insufficient failure statistics, which allows determining the reliability parameters of a complex system.

For both cases, the question of the integration of input and output data arises. As a solution, it is proposed to use fuzzification and defuzzification methods. Fuzzification allows integrating probabilities into linguistic BBN. It is theoretically possible to defuse linguistic BBN. However, this task may require resource costs.

For the second case, it is possible to use the fuzzification of the classical BBN, which is also a costly process. In this case, the most convenient approach is to defuse the output values obtained using the fuzzy method of analyzing failure trees.

As an example of the method application, the BBN is built to assess the safety of a NPP reactor, taking into account the state of sources of external and internal energy supply.

The main nodes are:

- a state node of the reactor;
- nodes of the state of two safety systems (RCIC, RPS);
- nodes of external and internal power supply;
- nodes of three digital substations;
- nodes for diesel generator and battery.

This BBN was built and researched using the Netica tool.

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