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Need for Reliability Assessment of Special Protection System

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Abstract

Special Protection System (SPS) are designed to detect one or more predetermined system conditions which causes power system disturbances and for those conditions it has to take some preplanned remedial actions. The failure of this system to identify the defined condition or its failure to take the predefined remedial action, could lead to very serious and costly consequences. In order to increase the transfer capability of the power network SPS is widely used since it assist the system operators in administering fast corrective actions. The purpose of this paper is to clarify the need of developing a systematic and comprehensive reliability framework for SPS. Different reliability assessment methods are discussed, and effort to deal with a similar problem in power system industry is summarized.

Index Terms: Special protection systems (SPS), reliability assessment, remedial action schemes, system protection schemes

1. Introduction

The demand of new transmission line is increasing in order to improve the power transfer capability of the transmission system. During the last few decades [1], most transmission system additions were designed to locally strengthen the network in response to demand growth or to connect capacity resources; few major transmission reinforcements have been made specially to strengthen the bulk transmission system. Thus, the transmission system is becoming more stressed by increased power transfers, resulting in some transmission line being often loaded at or near their extreme limits.

Therefore system operators and security coordinators are relying more on protection system to maintain the security of the transmission network.

Special protection systems (SPS) (also called remedial action schemes, RAS or system protection scheme) are used to detect abnormal or pre determined system condition which could lead to system contingencies and for those condition it will take pre-planned corrective actions. SPS assist the system operators in administering fast corrective actions. Also, the deployment of SPS is less expensive and easier than the addition of new transmission infrastructure. However excessive dependent on SPS may increase the risk to system security. According to NERC [2], SPS misoperation is defined as any operation that exhibits one or more of the following attributes.

- Failure to operate
- Unnecessary operation
- Unintended system response
- Failure to mitigate

When SPS is operating correctly, it can significantly maintain the system stability following a contingency. However, the failure of SPS leads to very serious and costly consequences. System disturbance report [3] produced annually by NERC disturbances analysis working group gives numerous examples of protection system problems.

In this study, we address consequences of SPS failure. We review several examples of actual SPS failure. Different methods for SPS reliability assessment along with specific recommendation are provided. Conclusions are drawn in last section.

2. Consequences of SPS Failure

One of the main concerns in the design and operation of an SPS is to ensure that the designated actions are highly reliable. CIGRE task force report 38.02.19[4] has classified the operations of SPS into one of the three categories: desirable operation, undesirable operation and failure to operate. If the consequence of the operation is less severe than the consequence had the SPS not operated, the operation is desirable. If the consequence of the operation is more severe than the consequence had the SPS not operated, the operation is undesirable. Undesirable operation may either be intended or unintended. A nuisance operation is an example of unintended case that SPS takes unnecessary action when there is no disturbance in the system. An SPS failure to operate occurs when the SPS fails to respond as designed to conditions for which it is supposed to operate.

The primary effects of SPS failure are generator instability, loss of load, system separation and voltage instability. In IEEE-CIGRE survey [5] it is clear that the cost of SPS failure is very high as most of the respondents selected the highest cost category when utilities were asked to estimate the cost of an operation failure of SPS. Also the cost of the false trips is generally much lower than the cost of failure of the SPS to operate when required. This implies, that even with the risk of misoperation, SPS installation is economically beneficial.

3. SPS Failure Examples

SPS are often regarded as a part of a defense plan against identified extreme contingencies. The Brazilian Defense Plan against extreme contingencies [6] was triggered by March 11, 1999 blackout that caused the loss of 25GW of load and was the most severe of the Brazilian electric system history. A new PLC-based SPS was designed to create controllability zones. The following are brief description of some SPS failure cases [7]:

1. WSCC–Northeast/Southeast Separation Scheme–April 4, 1988
Scheme: System Separation
Reason: Flaw in design (the scheme was susceptible to misoperation due to the short bursts of communications circuit noise)
Consequence: 1,902MW of generation was lost and 253MW of load was interrupted
2. NPCC–Hydro-Quebec–April 18-19, 1988
Scheme: Load Rejection
Reason: Hardware Failure
Consequence: System wide blackout
3. NPCC–Hydro-Quebec–Nov. 15, 1988
Scheme: Load Rejection
Reason: Hardware Failure
Consequence: 3,950MW of load was interrupted
4. British Columbia Hydro/TransAlta Separation–Jan. 7, 1990
Scheme: Controlled opening of lines
Reason: Not armed (inadvertently)
Consequence: It caused 230kV Cranbrook-Nelway circuit to trip on the subsequent swing and resulted in separation (islanding) of the eastern part of the BCHA/TAUC system from the Interconnection
5. Garrison–Taft 500kV No. 1 and 2 outages–Jan 8, 1990
Scheme: Var Compensation (trip two 500kV bus reactors)
Reason: Flaw in the logic design
Consequence: It caused the unnecessary dropping of generation at Hauser, Morony, and Ryan (119MW) as well as the loss of customer load (25MW) in Helena
6. SE Idaho/SW Wyoming Outage–Sept. 12, 1991
Scheme: Generator Rejection
Reason: Hardware failure (telemetry that automatically arms this scheme was out of calibration)
Consequence: It caused the loss of a second 345kV line which led to further loss of transmission by overload and out of step conditions
7. Pacific AC Intertie Separation–Nov. 17, 1991
Scheme: System Separation

Reason: Software failure in PG&E RAS programmable logic controller caused the delay in initiating remedial actions (also maybe hardware failure)
Consequence: Fail to separate WSCC system into two islands, but did not produce any severe problems (it was expected that there would be load lost and out of step conditions)
8. Minnesota–Wisconsin Interface 69 kV conductor burn down–Oct. 13, 1992
Scheme: Controlled opening of lines
Reason: Incorrect setting
Consequence: Two 69kV lines in the Northern States Power and Dairyland Power Cooperative service burned open causing the lines to fall to ground and trip out
9. MAPP & MAIN–Eastern MAPP–Western MAIN Interface Separation–Nov. 6, 1997
Scheme: Controlled opening of lines
Reason: Flaw in design (opened the circuit at an ampere level below its setting, possibly due to an unbalanced load)
Consequence: Resulted in low voltages in the south-western Wisconsin, eastern Iowa and western Illinois (Cordova), heavy loading in parallel, lower voltage transmission systems, and a large phase angle across the open tie at Arpin.
10. PGCIL–Talcher-Kolar HVDC Bi-pole–Feb. 29, 2012 [8]
Scheme: Load Rejection
Reason: Flaw in design
Consequence: The system frequency dipped from 49.47 Hz to 48.96 Hz
11. NPCC–Feb. 1, 2014 [9]
Scheme: Generation Rejection
Reason: An error in the programming logic of a breaker reclosing circuit caused the unintended triggering of the SPS
Consequence: Loss of three generators with a combined output of 474 MW

4. Methods for SPS Reliability Assessment

4.1 Reliability Block Diagram (RBD) method

In reliability block diagram (or network modeling), the system is represented by means of number of blocks connected in parallel, series or combination of series and parallel to make up the network. Each block represents the component that comprises the system. These blocks connected with lines to indicate operational dependency. The key step in the process of reliability modeling is to convert a physical system into a block diagram. As long as there is a path from left to right through the network the system is considered to be success. After modeling the rules of probabilities are used to evaluate the reliability of the system.

4.2 Fault Tree Analysis (FTA)

Fault tree analysis (FTA) which is often described as “top-down” approach, is a graphical representation of events in a tree-like structure and is used to determine various combination of hardware, software, logic and human error failures that could result in a specified risk or system failure. The procedure for fault tree modeling is to examine each possible event and connect set of events using proper Boolean logic gates. System failures are often referred to as top events. After the fault tree structure is fully developed, the failure rate data, which can be obtained from field experience or from industry published data, is employed to quantify the fault tree [10].

4.3 Markov Modeling

Markov modeling involves definition of all mutually exclusive success/failure states in a system. These are represented by labeled circles. The system can transition from one state to another whenever a failure or a repair occurs. Transition between states are shown with arrows and are labeled with appropriate failure or repair probability (often approximated using failures/repair rates) [10].Markov modeling consist of two major steps

- Examine the number of states the system can be in
- Connect those states with labeled transition rates

States are often denoted by circles and are connected with arrow.

4.4 Monte Carlo Simulations

Monte Carlo simulations observe the stochastic behavior of each component in calculating the reliability of the system. It involves the generation of an artificial history of the component of the system and the observation of that artificial history to draw inferences concerning the characteristics of the real system.

The probability of failure of each component is compared with the randomly generated values and determined that the component is in normal state or failure state. Using this component state, the system state is obtained by examining simple logic operation according to the structure of the studied system. Now using the system state the reliability of the system is calculated.

5. Recommendations

FTA, Markov modeling and RBD are the analytical methods generally used by the utilities to assure the required reliability standards were being met [5]. Considering computational complexity, feasibility of subsequent uncertainty and sensitivity analyses, the capability of detection of errors in the reliability model, complexity of the system, the available data and performance required, the methods for reliability assessment must be selected.

The RBD technique provides a very simple mathematics to quantify the reliability of SPS. With simplified equation approach, the reliability could be obtained easily but could yield conservative results [11]. FTA is much easier to model large and complex system as compared to Markov modeling. However Markov analysis can model all aspects that are important for SPS. MC simulations are generally more flexible when complex configurations and condition of SPS are considered, and the performance is difficult to be analyzed analytically. Also the accuracy of the result depends on the number of samples in MC simulation.

Many of the newer systems are digital, which means that both hardware and software failures must be evaluated. The current efforts in standards development are helpful in this regard. The NERC Reliability Standards contain six standards in the protection and control (PRC) series that specially pertain to SPS [12].

Survey on SPS similar to the survey conducted by CIGRE-IEEE [5] is necessary to track the growth and diversity of SPS, to identify the reliability analysis methods preferred by the utilities, to understand the factors that are important while installation of new SPS by the power industry.

6. Conclusion

SPS have been proved to be a quick and economic way of ensuring power system reliability, it also enhance the transmission capacity by enabling the system operation closer to stability limits. This SPS technology very much encourages the concept of optimizing the network resources, especially transmission usage, while supplying uninterrupted and economic power. The system operators willing to accept SPS would consider the SPS operational reliability issue. Unless the performance of SPS operations is assured highly reliable, it cannot totally remove the safety concerns for the new protection scheme. Thus, the impacts and risks of SPS events, such as the probability of failure to operate or misoperation should be carefully evaluated. Although the risks of SPS misoperation or failure to operate can be managed and reduced by redundancy and permissiveness techniques, power system planners, designers, engineers, need to understand the possible impact and make proper coordination based on cost or benefit analysis and reliability assessment.

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