

Catastrophic Failures in Power Systems: Causes, Analyses, and Countermeasures

JAIME DE LA REE, YILU LIU, LAMINE MILLI, ARUN G. PHADKE, AND LUIZ DASILVA

Invited Paper

Catastrophic failures of power systems are phenomena which occur with some regularity throughout the world. It is recognized that these cannot be prevented, although with the use of newer developments in power engineering, in communication systems, and in computer engineering it would be possible to reduce their frequency and their impact on society. Analyses of many blackouts point to some salient features which are common to most such events: power systems under stress because of high load levels or outages of important facilities, some initiating event—usually a fault, often followed by cascading effects due to unwanted operation of some protection systems. In particular, the role of hidden failures (HFs) in protection systems in propagating power system disturbances has become clearer with some of the recent research reported in the literature. This paper explores further the issue of HFs in protection systems and possible countermeasures.

Regarding the countermeasures, adapting the protection systems so that they would change their operational logic from ON to a VOTING protocol has been discussed in the literature, and is well within the capability of present technology. Other hardware solutions, such as "Hidden Failure Monitoring and Protection Systems," have also been discussed in the literature.

Most of these countermeasures will require intensive use of communication networks. Communication infrastructure will be utilized for real-time data transfer, as well as for slower speed data gathering tasks related to the condition of the power system. In this paper, we concentrate on the communication facilities and their applications for providing countermeasures against catastrophic failures of power systems.

Keywords—Cascading, catastrophic, countermeasures, failure, hidden, risk.

1. CAUSES AND ANALYSES OF POWER SYSTEM BLACKOUTS

A. Role of Hidden Failures (HFs) in Protection Systems

It is well known that protection systems play an important role in the manner in which a power system responds to cat-

astrophic events. Misoperation of protection systems is often a contributing cause to the cascading process encountered in major power system failures throughout the world. Among possible failures of the protection systems, the most troublesome are the "hidden" failures.

HFs in protection systems are defined as "a permanent defect that will cause a relay or a relay system to incorrectly and inappropriately remove a circuit element(s) as a direct consequence of another switching event" [1]. Note that a "failure to operate" is not considered to be an HF due to the fact that some other protection system will take out the faulted equipment. Protection systems are generally biased toward dependability, meaning that some protection will always be available to remove a fault from the power system. This bias is justified, because the effect of leaving a fault on for longer duration on an ac power system is to make the system unstable, which would ultimately lead to a catastrophic failure. The phenomenon of HFs in protection systems becomes particularly important in times of stress precisely because it weakens the security of the protection—meaning that it leads to unnecessary outages.

HFs in protection occur as a result of the following two phenomena [2].

- A protection element functionality defect (PEFD). This type of defect may be a result of hardware failures, outdated settings, or human errors.
- The second contributing factor is the logical arrangement of devices with the PEFD. The logic will determine if the failure will or will not remain hidden within the protection scheme until another event uncovers the defect.

As an example of an HF in a protection system, consider Fig. 1, the control circuit of a distance relay—one of the most commonly deployed protection system on transmission networks. The figure shows a simplified control circuit of three-zones of protection and the corresponding coordination timers for zones 2 and 3. For this protection system, a PEFD in the form of continuously closed contacts γ_2 or γ_3 will re-

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The authors are with Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0111 USA (e-mail: jree@vt.edu; yllu@vt.edu; milli@vt.edu; aphadke@vt.edu; ldasilva@vt.edu).

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