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Situation awareness in power systems: Theory, challenges and applications

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ABSTRACT

Due to the increasing size and operational complexity of modern power systems, transmission system operators often have difficulties forming a complete and accurate picture of the state of the part of the system for which they are responsible. These difficulties may prevent them from achieving the level of situation awareness (SA) that they need to make the right decisions and respond effectively to an incident. Inadequate SA has indeed been identified as one of the contributing factors in several recent large electrical disturbances worldwide. This paper first reviews the fundamentals of SA and then discusses the main sources of operator errors due to insufficient SA in power systems and how these affect the operational decision-making process. It then discusses tools and standards that can help system operators improve their level of SA. Finally, a generic procedure for achieving sufficient SA is presented, which aims to guide the design of an information system that is both technology- and user-oriented.

Contents

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1. Introduction

Numerous incidents in various domains demonstrate the importance of situation awareness (SA) in carrying out operations safely and reliably. For example, in 1989, a major aircraft accident occurred during take-off from an airport in Canada, because the pilot was not aware that a large amount of snow and ice on the wings, reduced the lift of the aircraft. This led to a loss of control and the crash of the aircraft [1]. Several power system blackouts, some of which are discussed in Section 2, also illustrate what can happen in a complex system, when the people involved in its operation are not fully cognizant of what they need to know. Driven by numerous similar incidents, organizations from different domains have developed advanced information systems to support the development of a sufficient SA.

Acquiring adequate SA is particularly critical during electrical disturbances. In general, the progress of a blackout can be divided into two main phases: the pre-cascading phase, where the situation evolves slowly enough that operators have time to react, and the cascading phase, where components trip so rapidly that operators are not able to respond in a timely manner and fast automatic devices take over when emergency action is required, either to protect components or to try to salvage part of the system using under-frequency load shedding. Panteli et al. [2] show that inadequate operators SA (OSA) has a significant impact on the probability of the system entering the cascading phase of a blackout. To prevent cascading outages it is therefore vitally important to support the effective and timely decision-making during the pre-cascading phase, before the situation becomes uncontrollable.

However, operating power systems is an extremely challenging task because of their size and complexity as well as the large number of contingencies that can occur. Operators should therefore be provided with the data and the information that they need to understand the current state of the system and be able to project its future behavior. Because power systems are getting increasingly interconnected, system operators need to be aware not only of the state of their own control area, but also of the state of neighboring control areas.

The aims of this paper are to review the fundamentals of SA, provide an overview of existing tools and methods for enhancing OSA, and discuss how OSA could be further improved in transmission control centers. Section 2 discusses the impact of situation awareness on the severity of recent major electrical disturbances. Section 3 defines SA and discusses the factors that influence it. Section 4 discusses the main sources of lack of SA in power system control centers. Section 5 discusses how the information required for operational decision-making is filtered by the ICT infrastructure and human perception. Section 6 reviews existing SA technologies, while a generic procedure for achieving adequate OSA is provided in Section 7. Section 8 summarizes and concludes the paper.

2. Role of situation awareness in recent major disturbances

Inadequate OSA has been identified as a contributing factor to the development and severity of recent electrical disturbances. In the Northeast USA blackout of 14th August 2003 [3], numerous failures in the information system, such as state estimator and alarm processing system, and a lack of information sharing between system operators led to a degraded OSA and consequently to a delayed response to the initial electrical failure, resulting in the spreading of the disturbance. In the Italian blackout of 28th September 2003 [4], insufficient information exchange between the Italian and Swiss operators prevented the development of a common understanding of the problem, which resulted in a lack of effective joint control actions and to the isolation and complete blackout of the entire Italian peninsula. In the UCTE system disturbance on 4th November 2006 [5], the operators based their decisions on empirical assessments without performing a contingency analysis using updated data. The problem was compounded by a lack of coordination between operators in different control centers. The initial electrical outage could then propagate and split the European Grid into three islands (West, North–East, and South–East), with a significant power imbalance in each area. Due to a lack of proper operational planning and adequate cognition of the evolving system conditions, part of the Western US Interconnection was operated in an N-1 insecure state. Following a routine electrical problem, this led to a blackout in Arizona and Southern California on 8th September 2011 [6].

The following main conclusions can be derived from these examples of blackouts where OSA played a key role:

- Despite the increasing use of automation, human operators remain an integral part of modern power systems.
- OSA is a key factor in preserving power system security. Inadequate OSA may result in a delayed, incorrect or deficient response by the operators to an electrical event or even cause errors during routine operational procedures, endangering power system reliability.
- It is critical to develop and maintain sufficient SA at the early stages of a disturbance, before the situation becomes uncontrollable. This enables effective and fast reaction by the operators, preventing cascading outages.
- As power systems have become highly interconnected, it is vitally important for the system operators to develop a wide-area SA that goes beyond the administrative borders of their control area. They need to be aware of events that may occur in neighboring networks, which even though they may be geographically distant, might be electrically close enough to affect the stability of their own network.

3. What is situation awareness?

Situation awareness has attracted the interest of researchers and practitioners in a variety of domains, including military [7], aviation [8,9], air traffic control [10], automotive [11] and C4i (command, control, communication, computers and intelligence) [12] and environment [13]. While early research on SA took place in the military and aviation domains, driven by the recognition that SA played a key role in numerous incidents in different domains, it has developed into a critical research theme in almost any area that involves humans performing tasks in complex and challenging environments. A distinction should be made between two main categories of SA: individual and team or shared SA.