INTERNATIONAL JOURNAL OF CRITICAL INFRASTRUCTURE PROTECTION 6 (2013) 197–216

Available online at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/ijcip

Using interconnected risk maps to assess the threats faced by electricity infrastructures

Gabriel J. Correa-Henao[a], *Jose M. Yusta*[b,*], *Roberto Lacal-Arántegui*[c]

[a]*Faculty of Engineering, Fundación Universitaria Luis Amigó, C/51A # 67B90, Medellín, Colombia*
[b]*Department of Electrical Engineering, Universidad de Zaragoza, C/María de Luna 3, Zaragoza 50018, Spain*
[c]*JRC-Institute for Energy, European Commission, P.O. Box 2, 1755 ZG Petten, the Netherlands*

ARTICLE INFO

Article history:
Received 13 December 2011
Received in revised form
6 September 2013
Accepted 6 October 2013
Available online 9 October 2013

Keywords:
Electricity infrastructure
Risk assessment
Interconnected risk maps

ABSTRACT

This paper describes a methodology for risk identification and risk assessment in electricity infrastructures. The approach leverages risk maps and can be applied to general infrastructure networks. A semi-quantitative assessment strategy that incorporates the creation of risk charts within a risk management framework is also presented. This strategy engages an intuitive graphical representation to identify the most significant threats affecting infrastructure networks. As a result, it is possible to conduct risk analyses of energy supply (and other) infrastructures within a region or country by engaging interconnected risk maps. The application of the methodology is demonstrated using a case study of a Colombian electricity infrastructure, which includes an estimation of the risk components.

1. Introduction

An integrated risk management cycle must adhere to the infrastructure protection guidelines specified in the United States National Infrastructure Protection Plan [1] or the European Programme for Critical Infrastructure Protection [2]. The frameworks established by these protection plans can be summarized in terms of a risk management plan that involves six steps: (i) establishment of safety goals; (ii) identification of resources and risks; (iii) assessment of risks; (iv) prioritization of actions; (v) implementation of protection programs; and (vi) measurement of effectiveness [3]. This paper proposes a conceptual framework for risk management in electricity infrastructures, which specifically addresses the various risks that affect electricity infrastructures, especially those related to electricity transmission and distribution. The methodology focuses on risk identification as well as risk evaluation, and also incorporates semi-quantitative assessments.

This paper is divided into two parts. The first part reviews risk identification as it relates to the electricity sector. It includes a brief description of state-of-the-art risk assessment strategies for electricity infrastructure owners and operators, with an emphasis on electricity transmission and distribution. Key concepts such as infrastructure protection plans, enterprise resources, risk maps and risk matrices are also described.

The second part of the paper describes the application of interconnected risk maps as the first step to implementing a risk management framework. A case study involving a Colombian electricity infrastructure is used to demonstrate the identification and assessment steps via the construction and validation of an interconnected risk map. A semi-quantitative technique involving risk charts is presented as a rapid and highly effective risk evaluation strategy that can be used within a risk management framework. The evaluation methodology is broad enough to cover short-term,

*Corresponding author. Tel.: +34 976 761 922; fax: +34 976 762 226.
E-mail address: jmyusta@unizar.es (J.M. Yusta).

1874-5482/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.ijcip.2013.10.002

medium-term and long-term threats and risks in the technical and non-technical categories. This facilitates the analysis of structural vulnerabilities in electricity infrastructures and the identification of situations that impact infrastructure protection more accurately than existing methods.

The paper also provides an inventory of risk components related to the electricity infrastructure. The inventory covers the nature of the risks and their components, origins, classification and assessment. The inventory is useful for validating the methodology presented in this paper and serves as a good reference source for critical infrastructure protection planning.

2. Risk management framework for electricity infrastructures

The critical infrastructure comprises the assets that are required for the functioning of a society and its economy, i.e., assets whose sudden non-availability could result in the loss of life or seriously impact health, economic systems or public security. This definition also applies to energy infrastructures, including those related to electricity generation, transmission and distribution.

2.1. *Infrastructure protection plans*

In 2005, a “green paper” entitled “European Programme for Critical Infrastructure Protection” was released by the European Commission [4]. In 2008, the European Council adopted Directive 2008/114/EC [2], which created the European Programme for Critical Infrastructure Protection (EPCIP). In 2009, the United States National Infrastructure Protection Plan (NIPP) [1] was launched, following the release of several frameworks established by the U.S. Department of Homeland Security [5–7]. Both EPCIP and NIPP clearly define the critical areas in which efforts must be focused in order to develop plans for threat prevention and infrastructure protection. Meanwhile, the governments of several countries have launched similar initiatives for critical infrastructure protection [3].

The frameworks established by Directive 2008/114/EC and NIPP can be summarized in terms of a risk management plan that involves six steps: (i) establishment of safety goals; (ii) identification of resources and risks; (iii) assessment of risks; (iv) prioritization of actions; (v) implementation of protection programs; and (vi) measurement of effectiveness. Feedback and continuous improvement are also part of the frameworks. Fig. 1 presents a risk management plan for critical infrastructure protection that conforms to the frameworks.

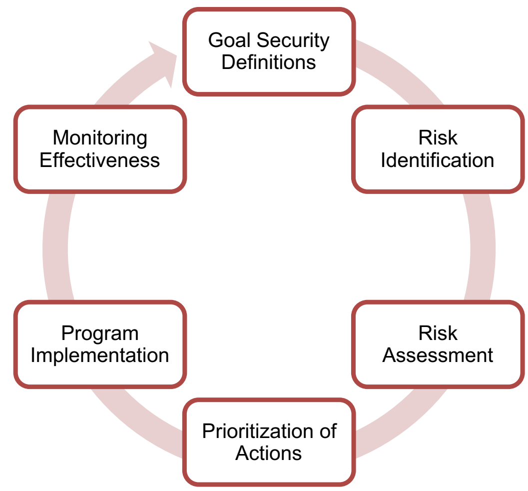

Fig. 1 – Risk management plan for critical infrastructure protection.

Infrastructure protection plans promote the use of risk management models that incorporate strategies for reducing uncertainty by exhaustively compiling and taking into account infrastructure asset data and infrastructure interrelationships. Infrastructure protection plans also suggest approaches for reaching the various stakeholders in the critical infrastructure value chain.

- **Identification of risks and resources**: This step involves the creation of an inventory of resources, assets, systems and networks in the infrastructure value chain. The step also involves the identification of risks affecting system resilience, which requires the development and maintenance of an inventory of physical infrastructure assets that includes property, information systems and considers technical and non-technical threats.
- **Risk assessment**: The most widely used and accepted technique involves qualitative risk assessment using risk assessment matrices that take into account the likelihood and the consequences of each risk [8–10]. The risk matrices are created with input from domain experts (through interviews and Delphi techniques). Quantitative risk assessment is performed using data and variables that allow statistical modeling. Quantitative risk assessment is typically focused on specific risks, especially the risks that could produce serious consequences.
- **Prioritization of actions and program implementation**: This step involves the comparison of the relative levels of risk, along with options to achieve the safety goals. Protection measures are applied where possible to reduce security risks in a cost-effective manner.
- **Monitoring effectiveness**: This step incorporates monitoring activities as a means to achieve regular supervision, e.g., by creating performance indicators. Many opportunities for change and improvement can be recognized during this step.

2.2. *Electricity infrastructure value chain*

The risks to the population and to the environment from energy systems arise from energy production as well as from the components in the value chain. In the case of electricity infrastructures, this includes power generation, high and medium voltage transmission, medium and low voltage distribution, power marketing and the provision of services to energy consumers (Fig. 2).

Specifying the value chain in electricity infrastructures is the first step to defining the objectives and policies for secure energy supply. The majority of critical infrastructure assets in