



CYPRESS

CYPRESS: Report D1.1 describing the selected performance metrics

Task 1.1 - Project Report

Efthymios Karangelos, Klaas Thoelen, Farshid Faghihi, Frédéric Sabot, Dave Singelée, Volkan Guler, Jonathan Francart, Pierre Henneaux, Hakan Ergun

Date: June 24, 2021

Contents

Contents	3
Executive Summary	6
1 Introduction	7
2 Electric Power Systems Background	9
2.1 Structure and subsystems	9
2.2 Organization and stakeholders	13
2.2.1 Electricity markets	13
2.2.2 Regionally-coordinated system operation	14
2.2.3 Main actors	14
2.2.4 Functional zones and hierarchical levels	15
2.3 Control and protection	15
2.3.1 Control system	15
2.3.2 Protection systems	20
2.4 Computational applications	22
2.4.1 Control Center	22
2.4.2 Substation Automation	24
2.4.3 Distributed Energy Resources Operation	25
2.4.4 Advanced Metering Infrastructure & Aggregated Prosumer Management	25
3 Communication Networks Background	27
3.1 OSI Reference Model	29
3.2 Internet Protocol Suite	30
3.2.1 Ethernet	31
3.2.2 IP	32
3.2.3 UDP and TCP	33
3.3 Network Reliability	33
3.4 Smart Grid Protocols	35
3.4.1 IEC 61850	35
3.4.2 IEC 60870	36
3.4.3 Modbus	36
3.5 Further Reading	37

4	Definition of Reliability, Resilience and Cybersecurity	39
4.1	Electric Power System Reliability	39
4.1.1	Adequacy	39
4.1.2	Security	40
4.1.3	Reliability Management	41
4.2	Electric Power System Resilience	44
4.3	Cybersecurity	45
4.3.1	Definitions	45
4.3.2	General discussion on the concept of cybersecurity	45
4.3.3	Information security objectives	47
4.3.4	Attacker model	52
4.3.5	Attacks	53
4.3.6	End-to-end cybersecurity analysis	54
5	Reliability and resilience metrics	61
5.1	Reliability metrics	61
5.1.1	State-of-the-art adequacy metrics	62
5.1.2	State-of-the-art security metrics	64
5.1.3	State-of-the-art reliability metrics	65
5.1.4	Selection of reliability metrics for the CYPRESS project	66
5.2	Resilience metrics	68
5.2.1	State-of-the-art resilience metrics	68
5.2.2	Selection of resilience metrics for CYPRESS project	72
6	Cybersecurity metrics	79
6.1	Introduction	79
6.2	Standards and Methodologies	79
6.2.1	NISTIR 7628	79
6.2.2	ISO/IEC 27001/27000 Series	80
6.2.3	IEC 62351	81
6.2.4	IEEE 1686	82
6.3	Cybersecurity Metrics	82
6.3.1	The Need for Cybersecurity Metrics	82
6.4	Selection of Cybersecurity Metrics for CYPRESS Project	82
6.4.1	Domain 2: Asset security	83
6.4.2	Domain 3: Security Architecture and Engineering	83
6.4.3	Domain 4: Communication and Network Security	83
6.4.4	Domain 5: Identity and Access Management	84
6.4.5	Domain 7: Security Operations	84
	Bibliography	87

Executive Summary

This document is the first deliverable of the "*Cyber-Physical Risk of the bulk Electric Energy Supply System*" (CYPRESS) project.

The CYPRESS project aims at developing novel knowledge, methods and tools needed to help ensure the security of supply through the transmission grid, while accounting for the specific nature of cyber-threats and integrating them into a coherent probabilistic risk management approach. It is articulated along three research themes, aiming to develop: i) novel models and benchmarks for computer simulation and laboratory testing of the cyber-physical electric power system security of supply, ii) techniques for assessing the cyber-physical security of electric energy supply, and iii) techniques for enhancing the cyber-physical security of electric energy supply. The project scope falls entirely within the category of "fundamental research" within the meaning of Regulation (EU) No 651/2014 because it is experimental and theoretical work undertaken essentially with a view to acquire new knowledge on the foundations of phenomena or observable facts. The project is not intended to develop commercial tools.

The work presented in this document has been performed in the frame of CYPRESS WP1, titled "*Criteria and benchmarks for cyber-physical risk management*". The objective of CYPRESS WP1 is to generalize and adapt the concepts currently used in reliability management of electric power and energy systems so that they can correctly cover the cyber-threats from various system wide control and communication layers. The document is the outcome of task 1.1, seeking to develop relevant performance metrics to quantify the overall level of cyber-security, resilience and reliability of a bulk electric power system and to quantify how these properties decompose over the different subsystems, such as national transmission grids, generation systems, and lower voltage distribution grid.

As task 1.1 was the first activity in the CYPRESS project, the need to first establish a common understanding of the basic concepts in electrical energy physical and cyber systems, and to share bibliographic resources, became apparent. Rather than achieving this shared understanding implicitly, the onset of this report first provides essential background on electric power systems (Chapter 2) and communication networks (Chapter 3), as well as the conceptual definitions of reliability, resilience and cyber-security (Chapter 4). The report subsequently introduces relevant reliability and resilience metrics that are presently used by the electric power system stakeholders as well as prominent proposals from the scientific literature (Chapter 5) and relevant cyber-security metrics (Chapter 6). It must be noted that the focus has been placed on the clear introduction of such metrics, and on establishing their relevance for the research scope of the CYPRESS project. The applicability of these metrics over different subsystems (*e.g.*, national transmission grids, lower voltage distribution grids, *etc.*) is also presented. Defining the precise decomposition approach for such metrics is a topic that has to be followed up at a latter stage, and while precisely developing the proposed methodologies

for cyber-physical risk assessment and risk management in electric power systems.

Author contributions

Table 1 lists all the authors that have contributed to this report. Efthymios Karangelos¹ wrote chapter 1, co-wrote chapters 2, 4 and 5 and is the main editor of the report. Klaas Thoelen took the lead in writing Chapter 3, proof-read the entire document and provided related feedback for improvements and corrections. Farshid Faghihi co-wrote chapters 2 and 5. Frédéric Sabot co-wrote chapters 2 and 5. He also contributed to the discussions for all power system-related parts, and reviewed the whole document. Dave Singelée and Volkan Guler wrote chapter 4 and co-wrote 6. Jonathan Francart provided inputs to chapters 4 and 6. Pierre Henneaux and Hakan Ergun reviewed the entire document and provided feedback.

Author	Affiliation
Efthymios Karangelos (Task leader)	Université de Liège
Klaas Thoelen	Katholieke Universiteit Leuven
Farshid Faghihi	Université libre de Bruxelles
Frédéric Sabot	Université libre de Bruxelles
Dave Singelée	Katholieke Universiteit Leuven
Volkan Guler	Katholieke Universiteit Leuven
Jonathan Francart	Université de Liège
Pierre Henneaux	Université libre de Bruxelles
Hakan Ergun (Work-package leader)	Katholieke Universiteit Leuven

Table 1: List of Authors

¹Corresponding author: e.karangelos@uliege.be.

This project is supported by the Belgian Energy Transition Fund

