



BSI Standards Publication

Power systems management and associated information exchange — Data and communications security

Part 12: Resilience and security recommendations
for power systems with distributed energy
resources (DER) cyber-physical systems

National foreword

This Published Document is the UK implementation of IEC/TR 62351-12:2016.

The UK participation in its preparation was entrusted to Technical Committee PEL/57, Power systems management and associated information exchange.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2016.

Published by BSI Standards Limited 2016

ISBN 978 0 580 92310 4

ICS 33.200

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 30 April 2016.

Amendments/corrigenda issued since publication

Date	Text affected
-------------	----------------------



TECHNICAL REPORT



**Power systems management and associated information exchange – Data and communications security –
Part 12: Resilience and security recommendations for power systems with distributed energy resources (DER) cyber-physical systems**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.200

ISBN 978-2-8322-3255-2

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	6
INTRODUCTION.....	8
1 Scope.....	10
2 Normative references.....	10
3 Terms and definitions	11
4 Abbreviations and acronyms	12
5 DER architectures and DER cyber-physical concepts	13
5.1 Resiliency challenge for power systems with DER systems	13
5.2 Five-level DER hierarchical architecture	14
5.3 DER system interfaces	17
5.4 Resilience at different DER architectural levels	18
5.5 DER Systems as cyber-physical systems.....	19
5.5.1 Protecting cyber-physical DER systems.....	19
5.5.2 Cyber-physical threats	20
5.5.3 Resilience measures for cyber-physical systems.....	21
6 Threats, vulnerabilities, and impacts on power system resilience	23
6.1 Threats – engineering and cyber	23
6.1.1 Physical and electrical threats – mostly but not entirely inadvertent.....	23
6.1.2 Cyber threats – inadvertent and deliberate	23
6.2 Vulnerabilities – engineering and cyber vulnerabilities.....	26
6.2.1 General	26
6.2.2 Power system vulnerabilities and attacks.....	26
6.2.3 Cyber security vulnerabilities and attacks	28
6.3 Risk management and mitigation techniques.....	30
6.3.1 Risk handling	30
6.3.2 Risk mitigation categories	31
6.4 Impacts on power system resilience.....	33
6.4.1 Safety impacts	33
6.4.2 Power outage impacts.....	34
6.4.3 Power quality impacts	35
6.4.4 Financial impacts	35
6.4.5 Regulatory and legal impacts	36
6.4.6 Environmental impacts	36
6.4.7 Goodwill and other “soft” impacts	36
6.5 DER stakeholders' resilience responsibilities	36
6.6 Resilience Measures for DER systems to counter threats.....	37
6.6.1 General IT cyber security approach for DER systems.....	37
6.6.2 Resilience by engineering designs and operational strategies	38
7 Level 1 DER System resilience recommendations	38
7.1 General.....	38
7.2 Level 1 DER system: architecture	38
7.3 Level 1 DER system: vulnerabilities	40
7.3.1 General	40
7.3.2 Cyber vulnerabilities.....	40
7.3.3 Engineering design and development vulnerabilities	40

7.3.4	Deployment and operational vulnerabilities	41
7.4	Level 1 DER system: impacts	41
7.5	Level 1 DER system: resilience recommendations	44
7.5.1	General	44
7.5.2	Manufacturer: DER system design for resilience recommendations	44
7.5.3	Integrator and installer: DER setup for meeting resilience recommendations.....	45
7.5.4	Testing personnel: resilient DER system interconnection testing recommendations.....	47
7.5.5	DER user: access recommendations	48
7.5.6	ICT designers: requirements for local DER communications.....	48
7.5.7	Security managers: alarming, logging, and reporting cyber security recommendations.....	50
7.5.8	Maintenance personnel: resilience recommendations for maintenance, updating and re-testing, systems	50
7.5.9	Recommended coping actions during an attack or failure	51
7.5.10	Recommended recovery and analysis actions after an attack or failure.....	52
8	Level 2: Facilities DER energy management (FDEMS) resilience recommendations	52
8.1	Level 2 FDEMS: architecture	52
8.2	Level 2 FDEMS: Vulnerabilities.....	54
8.3	Level 2 FDEMS: Impacts	54
8.4	Level 2 FDEMS: Resilience recommendations	56
8.4.1	General	56
8.4.2	Manufacturer: Design of FDEMS resilience recommendations	56
8.4.3	Integrators and installer: FDEMS implementation for meeting resilience recommendations.....	57
8.4.4	Testing personnel: Resilient FDEMS testing recommendations.....	60
8.4.5	FDEMS users: Access recommendations.....	60
8.4.6	FDEMS ICT designers: Resilience recommendations	61
8.4.7	Security managers: Alarming, logging, and reporting recommendations.....	63
8.4.8	Maintenance personnel: Resilience recommendations for maintenance, updating and re-testing, systems	63
8.4.9	Recommended coping actions during an attack or failure	64
8.4.10	Recommended recovery and analysis actions after an attack or failure.....	65
9	Level 3: Third parties: Retail energy provider or aggregators resilience recommendations	66
9.1	Level 3: Third parties: ICT architecture	66
9.2	Level 3: Third parties: ICT vulnerabilities	67
9.3	Level 3: Third parties: ICT impacts	68
9.4	Level 3: Third parties ICT: Resilience recommendations	69
9.4.1	Third party ICT designers: Resilience recommendations	69
9.4.2	ICT users: Access recommendations	71
10	Level 4: Distribution operations analysis resilience recommendations	72
10.1	Level 4 DSO analysis: Architecture	72
10.2	Level 4 DSO analysis: Vulnerabilities.....	73
10.3	Level 4 DSO analysis: Impacts	74
10.4	Level 4 DSO analysis: Resilience recommendations	76
10.4.1	Resilient design of distribution grid equipment with DER systems.....	76
10.4.2	Resilience through DSO grid operations with DER systems.....	76

10.4.3	Resilience through power system analysis	77
10.4.4	Resilience by stakeholder training	78
Annex A (informative)	NISTIR 7628 Smart Grid Catalog of Security Requirements	79
A.1	NISTIR 7628 families of security requirements	79
A.2	Detailed NISTIR 7626 Catalogue of Smart Grid Security Requirements	80
Annex B (informative)	IT security guidelines	85
B.1	Overview of cyber security issues for DER systems	85
B.2	Security guidelines and policies across organizational boundaries.....	85
B.3	User and device authentication.....	87
B.4	Good practices for specifying and implementing cryptography	89
B.5	Cryptographic methods	90
B.6	Cryptography used for transport layer security on networks.....	91
B.7	Wireless cryptography	92
B.8	Key management using Public Key Cryptography.....	92
B.9	Multicast and group keys.....	94
B.10	Device and platform integrity	94
B.11	Resilient network configurations	94
B.12	Network and system management (NSM).....	95
B.13	Some additional cyber security techniques.....	95
B.14	Security testing procedures	95
B.15	Security interoperability.....	96
Annex C (informative)	Mapping between IEC 62443-3-3, NISTIR 7628, and IEC TR 62351-12.....	97
C.1	Mapping table	97
C.2	IEC TR 62351-12 cyber security items not mapped to all guidelines	103
Annex D (informative)	Glossary of terms	106
Bibliography	107

Figure 1 – Smart grid resilience: intertwined IT cyber security and engineering strategies	9
Figure 2 – Smart Grid Architecture Model (SGAM).....	15
Figure 3 – Five-level hierarchical DER system architecture	16
Figure 4 – Structure of use cases within the DER hierarchy	19
Figure 5 – Mitigations by engineering strategies and cyber security measures.....	21
Figure 6 – Security requirements, threats, and possible attacks	30
Figure 7 – Level 1: Autonomous DER systems at smaller customer and utility sites	39
Figure 8 – Level 2 FDEMS architecture	53
Figure 9 – DER third parties: Retail energy provider or aggregators architecture	67
Figure 10 – Distribution operations architecture	72
Table 1 – Examples of mitigations by engineering strategies and cyber security techniques.....	22
Table 2 – Engineering and cyber security data for managing the resilience of DER systems.....	22
Table 3 – Examples of mitigation categories for cyber-physical systems	32
Table 4 – Level 1 impact severities due to attacks and failures of autonomous DER systems.....	43

Table 5 – Level 2 impact severities due to malicious attacks and failures of FDEMS.....55

Table 6 – Level 3 impact severities due to malicious attacks and failures of DER ICT.....69

Table 7 – Level 4 impact severities due to malicious attacks and failures of DMS or
DERMS75

Table A.1 – NIST Smart Grid Security Requirements Families79

Table A.2 – Detailed NIST Catalogue of Smart Grid Security Requirements80

Table C.1 – Mapping between IEC 62443-3-3, NISTIR 7628, and IEC TR 62351-1298

Table C.2 – IEC 62351-12 cyber security items not mapped to all guidelines..... 104

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**POWER SYSTEMS MANAGEMENT AND ASSOCIATED INFORMATION
EXCHANGE – DATA AND COMMUNICATIONS SECURITY –****Part 12: Resilience and security recommendations for power systems
with distributed energy resources (DER) cyber-physical systems**

FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

IEC TR 62351-12, which is a technical report, has been prepared by IEC technical committee 57: Power systems management and associated information exchange.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
57/1637/DTR	57/1664/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62351 series, under the general title: *Power systems management and associated information exchange – Data and communications security*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

Resilience and Cyber Security

In the energy sector, two key phrases are becoming the focus of international and national policies: “grid resilience” and “cyber security of the cyber-physical grid”. Grid resilience responds to the overarching concern: *“The critical infrastructure, the Smart Electric Grid, must be resilient – to be protected against both physical and cyber problems when possible, but also to cope with and recover from the inevitable disruptive event, no matter what the cause of that problem is – cyber, physical, malicious, or inadvertent.”*

*“Grid resilience ... includes hardening, advanced capabilities, and recovery/reconstitution. Although most attention is placed on best practices for hardening, resilience strategies must also consider options to improve grid flexibility and control.”*¹ Resilience of the grid is often associated with making the grid able to withstand and recover from severe weather and other physical events, but resilience should also include the ability of the cyber-physical grid to withstand and recover from malicious and inadvertent cyber events.

Resilience, sometimes defined as *“the fast recovery with continued operations from any type of disruption”* can be applied to the power system critical infrastructure. A resilient power system is designed and operated not only to prevent and withstand malicious attacks and inadvertent failures, but also to detect, assess, cope with, recover from, and eventually analyze such attacks and failures in a timely manner while continuing to respond to any additional threats.

The “cyber-physical grid” implies that the power system consists of both cyber and physical assets that are tightly intertwined. Both the cyber assets and the physical assets must be protected in order for the grid to be resilient. But protection of these assets is not enough: these cyber and physical assets must also be used in combination to cope with and recover from both cyber and physical attacks into order to truly improve the resilience of the power system infrastructure.

Background to Resilience Issues

All too often, cyber security experts concentrate only on traditional “IT cyber security” for protecting the cyber assets, without focusing on the overall resilience of the physical systems. At the same time, power system experts concentrate only on traditional “power system security” based on the engineering design and operational strategies that keep the physical and electrical assets safe and functioning correctly, without focusing on the security of the cyber assets. However, the two must be combined: resilience of the overall cyber-physical system must include tightly entwined cyber security technologies and physical asset engineering and operations, combined with risk management to ensure appropriate levels of mitigation strategies.

As an example, distributed energy resources (DER) systems are cyber-physical systems that are increasingly being interconnected to the distribution power system to provide energy and ancillary services. However, distribution power systems were not originally designed to handle these dispersed sources of generation, while DER systems are generally not under direct utility management or under the security policies and procedures of the utilities. Many DER systems provide energy from renewable sources, which are not reliably available at all times. Therefore, the resilience of power systems to even typical disruptions is increasingly at risk as more of these DER systems are interconnected.

¹ *“Economic Benefits of Increasing Electric Grid Resilience to Weather Outages,”* Executive Office of the US President, August 2013. See: http://www.smartgrid.gov/sites/default/files/doc/files/Grid%20Resilience%20Report_FINAL.pdf.

On the other hand, the sophisticated cyber-physical capabilities of smart DER systems could actually improve power system resilience if these smart DER capabilities were properly secure and coordinated with power system management through communications. DER systems can actually compensate for some of the problems they cause, such as riding through temporary spikes and dips in voltage or frequency that could be caused by their fluctuating behavior. DER functions such as volt-VAr management can smooth these fluctuations as well. In addition, networked DER systems (e.g. microgrids), and the bulk power system can serve as mutual backups during excessive peak loads or during disaster conditions. As illustrated in Figure 1, if both the cyber and the physical components of these DER systems were well designed and implemented with embedded cyber security, and were interconnected and operated using good engineering strategies, they would significantly improve the resilience of the power system.

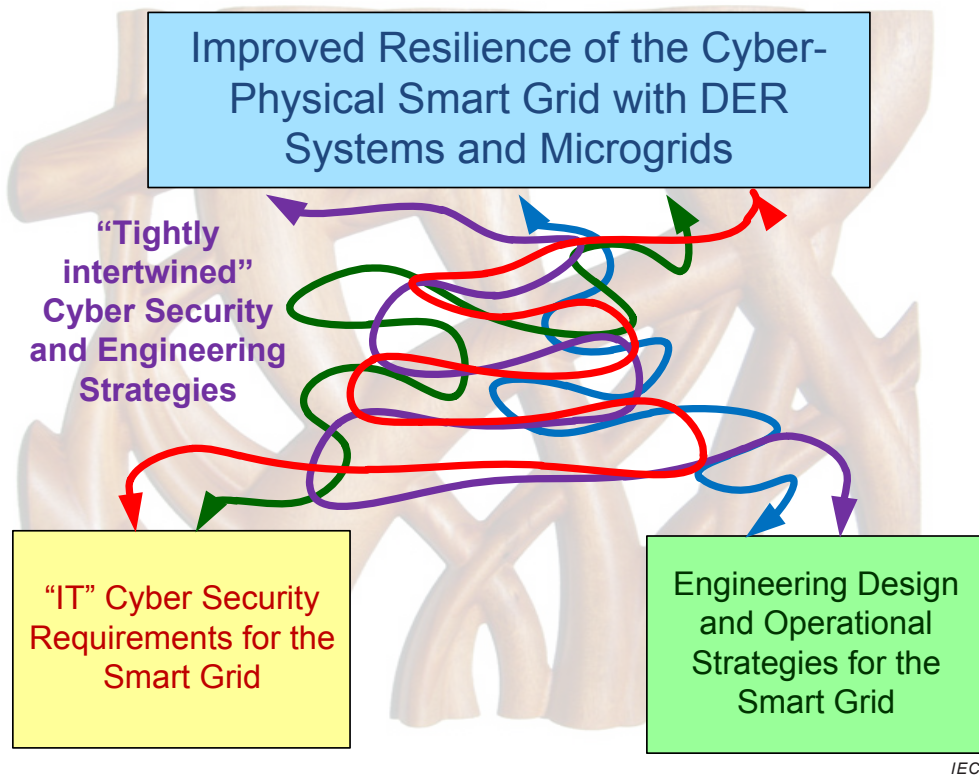


Figure 1 – Smart grid resilience: intertwined IT cyber security and engineering strategies

It is not just the utilities who must take responsibility for achieving this resilience goal. Many stakeholders are involved in the design, implementation, and operation of DER systems, including manufacturers, integrator/installers, users, information and communication technology (ICT) providers, security managers, testing and maintenance personnel, and ultimately utility regulators. However, given this new cyber-physical environment, often these stakeholders do not fully understand or appreciate the types of cyber security and engineering strategies that could or should be used.

POWER SYSTEMS MANAGEMENT AND ASSOCIATED INFORMATION EXCHANGE – DATA AND COMMUNICATIONS SECURITY –

Part 12: Resilience and security recommendations for power systems with distributed energy resources (DER) cyber-physical systems

1 Scope

This part of IEC 62351, which is a technical report, discusses cyber security recommendations and engineering/operational strategies for improving the resilience of power systems with interconnected Distributed Energy Resources (DER) systems. It covers the resilience requirements for the many different stakeholders of these dispersed cyber-physical generation and storage devices, with the goal of enhancing the safety, reliability, power quality, and other operational aspects of power systems, particularly those with high penetrations of DER systems.

The focus of this technical report is describing the impact of DER systems on power system resilience, and covers the cyber security and engineering strategies for improving power system resilience with high penetrations of DER systems.

While recognizing that many other requirements exist for improving power system resilience, this technical report does not address general power system configurations, operations, manual power restoration activities or the many other non-DER-specific issues. For instance, power system reliability relies on well-coordinated protective relays, stable power system designs, and well-trained field crews, while control center cyber security relies on many best practices for communication network design and firewalls. However, this technical report only addresses the additional reliability and resilience issues caused by 3rd-party managed DER systems which may not be as well-secured or operated with the same reliability as the utility-managed power system.

This technical report discusses the resilience issues for cyber-physical DER systems interconnected with the power grid, building on the concepts and the hierarchical architecture described in the Smart Grid Interoperability Panel (SGIP) draft *DRGS Subgroup B White Paper – Categorizing Use Cases in Hierarchical DER Systems 01-14-2014.docx*².

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62351-9, *Power systems management and associated information exchange – Data and communications security – Part 9: Cyber security key management for power system equipment*³

² <http://members.sqip.org/apps/org/workgroup/sqip-drqs-b/download.php/2984/DRGS%20Subgroup%20B%20White%20Paper%20-%20Categorizing%20Use%20Cases%20in%20Hierarchical%20DER%20Systems%2001-14-2014.docx>

³ Under consideration.